Federal/Provincial Methanol Vehicle Test Program

Ontario

Ministry of
Transportation and
Communications

Transportation
Technology and
Energy Division

Transport Canada
Road Safety

Transports Canada
Sécurité routière

Federal/Provincial Methanol Vehicle Test Program

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Published by:
The Transportation Technology and Energy Division
Ontario Ministry of Transportation and Communications
Hon. James W. Snow, Minister
H.F. Gilbert, Deputy Minister

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March 1983

PROGRAM SUPPORT AND ACKNOWLEDGEMENTS

This program commenced in August, 1979, and has been carried out in the Chassis Dynamometer Facility of the Ontario Ministry of Transportation and Communications (MTC) at Downsview, Ontario. The program has been supported jointly by MTC and by the Federal Department of Transport (Transport Canada) under DSS Contract 18ST.T8080-9-2413, Serial No. OST-00028, as amended March 15, 1982.

Acknowledgements are due as follows:

- G.B. Maund, formerly with Transport Canada, now with EMR -- program definition, monitoring and vehicle procurement.
- V.C. Battista, Transport Canada -- program monitoring.
- C.E. Simmons, MTC -- supervision of vehicle preparation; design and construction of special instruments, components and fittings; overall test supervision.
- N. Perfect, MTC -- supervision of Dynamometer Facility.
- MTC Workshop and Dynamometer staff -- installation of fittings and instrumentation, running of Dynamometer tests.

In addition, special acknowledgement is due to the following:

- P. Ashton, Canadian Methanol Canadien, Winnipeg, through whose agency a special prototype VW Golf Methanol Vehicle was imported from Germany.
- G.W. Kandel, White Engines Inc. Canton, Ohio for the loan of the White/Texaco Stratified Charge Gremlin and for additional developmental work on the vehicle.
- Engineering staff from Texaco, Inc. and Stanadyne for advice and assistance related to the above vehicle.

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SUMMARY

Three gasoline vehicles, the Honda Accord, the VW Rabbit, and the Ford Fairmont have completed testing with gasoline, and with 10% and 15% methanol mixtures in gasoline. The fuel mixtures were straight additions with unleaded gasoline and were uncorrected for vapour pressure increase.

Testing has comprised chassis dynamometer measurements of fuel consumption, emissions and driveability. In addition, vehicles have been placed in road service and retested to assess some of the effects of longer-term exposure to methanol-containing fuels.

The use of 10% methanol in the above engines, designed for gasoline, was acceptable with respect to emission standards, fuel consumption and driveability, though a timing adjustment was necessary in one case (Honda). The use of 15% methanol caused emissions to exceed the Canadian Standard in two cases (Honda, VW). One of the vehicles, the VW Rabbit, showed significant component degradation from exposure to methanol-containing fuels.

An experimental White/Texaco stratified-charge multifuel engine has also undergone tests. The fuels used were gasoline, ethanol, methanol and 70% methanol in gasoline. Though the vehicle operated smoothly with all these fuels, yielding identical energy efficiency, the power levels were unsatisfactory because the fuel pump was inadequately sized for the alcohols. Though the multifuel engine concept is very advantageous, further development needs to be done on the prototype to develop a fuel injection pump capable of handling fuels of different energy densities while supplying adequate power.

Finally, a VW Golf designed for methanol fuel was tested. The vehicle showed improved efficiency compared with the VW Rabbit running on gasoline, corresponding to between 2.5 and 11.5% less energy consumption depending on air-fuel ratio setting and fuel composition. Significant concentrations of unburnt fuel emissions were observed which nominally exceed the Canadian Standard (2 g/mi) and significant levels of aldehydes

(0.7 - 0.8 g/mi) were also measured. However, the vehicle was not designed for Canadian conditions and it is likely that standard emission control techniques would reduce these emissions substantially. Cold-start performance does not currently match the standards of North American gasoline vehicles.

1/ INTRODUCTION

Methanol has been identified as the most likely synthetic liquid fuel that can be made from resources available in Canada -- including both fossil resources such as coal and natural gas and renewable resources such as biomass.

The behaviour of fuels containing methanol in spark ignition engines has been the subject of many investigations, particularly over the last decade. A number of reviews and surveys have been produced including a report by the R & D Division, MTC, which included references up to 1977 [1];* References 2 and 3 are more recent reviews. In addition, a Bibliography is appended to the end of the report listing a number of recent laboratory-based test reports and analyses dealing with the combustion of methanol-based fuels in spark ignition engines.

Methanol and gasoline are quite different in chemical and physical properties. Most of the problems associated with using existing engines designed for gasoline or adapting existing technology arise from these differences, thus:

- **Air/Fuel Ratios (A/F) and Energy Content** -- Methanol, being already partially oxygenated, requires less oxygen (air) for complete combustion. The stoichiometric air/fuel ratios are 14.7 for gasoline and 6.45 for methanol and the heat of combustion of methanol is about half that of an equal volume of gasoline.

- **Volatility, Miscibility and Materials Tolerance** -- Because of the different chemical nature of methanol and hydrocarbons (polar as against non-polar), mixtures of the two are very non-ideal and show an enhanced vapour pressure. At the same time, the latent heat is greater than for gasoline alone. Miscibility between methanol and hydrocarbons is diminished by lower temperatures and water contamination. Materials used in the construction of gasoline engines are often chemically degraded by methanol and methanol/gasoline mixtures.

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*Numbers in square brackets represent references which are listed at the end of the report.

- **Inflammability Limits** -- Methanol and methanol/gasoline mixtures can burn with a greater excess of air

- **Octane Properties**-- Methanol by itself has a higher octane rating and permits higher compression ratios with greater energy efficency than gasoline. Mixtures also show this property, depending on the engine and test conditions.

Because of the differences between methanol and gasoline, there are two main ways of using methanol as a fuel in a vehicle -- either mixed in low percentages with gasoline, or as a straight fuel by itself. It can be used as a mixture in the existing fleet of gasoline vehicles but with attendant problems due to the risk of phase separation of the mixture caused by water contamination. In addition, corrosion and degradation of some of the component materials (particularly plastics) may occur, and there may be some loss in performance (driveability) in vehicles designed and calibrated for gasoline. Use of the straight methanol fuel (which in practice may contain small percentages of components such as hydrocarbons to raise volatility) avoids the problems associated with the handling and storage of blends. However, complete recalibration of the carburetor is a minimum requirement (to allow for the doubled fuel flow necessary), and proper performance needs a major engine design change.

Because there are advantages and disadvantages associated with both modes of methanol use, the objective of this project was to examine the performance acceptability of either blends or straight methanol fuels, as appropriate. Five vehicles were chosen incorporating various features of advanced engine design, some of which might be expected to be more common in the future vehicle fleet. These are described in Table 1, together with the types of tests and fuels involved.

Acceptability is based on chassis dynamometer tests of vehicle emissions, fuel consumption and driveability. Fuel handling problems and component durability problems are not part of the present study but laboratory studies in these areas have been carried out under separate contracts [4, 5].

Table 1/ Vehicle Characteristics and Test Fuels Used

VEHICLE	ENGINE CHARACTERISTICS	FUELS				
		GASOLINE	10% METHANOL (M10)	15% METHANOL (M15)	INTERMEDIATE MIXTURES	90%-100% METHANOL (M90,M100)
HONDA ACCORD 1977	1.6 L, 8.4:1 C.R. CVCC Stratified charge; prechamber with auxiliary inlet valve and carburetor. No EGR. No catalyst.	x	x	x		
VW RABBIT 1977	1.6 L, 8:1 C.R. Mechanical continuous-port fuel injection. No EGR. No catalyst.	x	x	x		
WHITE/TEXACO GREMLIN	2.6 L, 12:1 C.R. Stratified charge direct fuel injection; swirl-flow inlet ports; cupped piston; EGR; catalyst.	x			70% methanol (M70)	x
FORD FAIRMONT California Emission Package 1980	2.3 L, 8.5 C.R. Exhaust-oxygen sensor, feedback-controlled carburetor, EGR. Three-way catalyst.	x	x	x		
VW GOLF Methanol 1981	1.6 L, 12.5:1 C.R. Carburetor factory converted for methanol. No EGR. No Catalyst.					x

2/ VEHICLE CHARACTERISTICS

The vehicles and fuels used in the testing are briefly described in Table 1. They all have engines which embody various features of advanced design, some of which may become common in the future.

2.1/ Honda CVCC

This engine is based on the stratified-charge concept [6] in which the fuel mixture is deliberately made non-homogeneous in the cylinder-head space. An auxiliary inlet valve and auxiliary carburetor are used to induct a proportion of the fuel as a rich mixture into a specially-shaped pre-chamber in the head. The rich mixture is easily ignited by the spark, and the flame produced projects into the rest of the cylinder head space containing the rest of the fuel as a lean mixture.

This engine concept combines the fuel economy and emission benefits of lean operation and the firing characteristics of rich operation and in this particular case eliminates the need for emission control equipment.

The carburetors are conventional with fuel at low pressure vented to atmosphere in the float bowls.

2.2/ VW Rabbit

This uses the Bosch K-Jetronic fuel injection system. Fuel is injected continuously into the inlet ports of each cylinder and the fuel flow-rate is governed mechanically by an airflow measuring device to maintain the correct air/fuel ratio. A closed fuel system is used at a pressure of 300 to 500 kPa, with excess fuel being returned to the tank.

2.3/ Ford Fairmont

This engine uses a carburetor acting under feedback control. An oxygen sensor in the exhaust stream supplies a signal to control the fuel flow so that the air/fuel ratio is maintained at equivalence ratio unity. This optimizes the operation of the catalyst in reducing hydrocarbons,

carbon monoxide and nitrogen oxides. The carburetor is otherwise a conventional type with a low-pressure fuel supply, vented to atmosphere in the float bowl.

2.4/ White/Texaco Gremlin

This is a direct-injected stratified charge (DISC) design [7]. Fuel is injected at high pressure directly into the cylinder head during the compression stroke. Swirl flow is induced in the intake air by specially-contoured inlet ports and a cupped piston, and ignition of the fuel jet is maintained by a long-duration oscillatory spark discharge.

This engine has wide fuel tolerance with no particular ignition quality requirement (octane or cetane number) or volatility specification limit. The fuel supply is under high pressure, above 10 000 kPa, with excess fuel being returned to the tank.

2.5/ VW Golf Methanol Vehicle

This engine uses a conventional carburetor modified for increased fuel flow. Extra heating is also applied to the fuel mixture in the manifold to help evaporation, and the compression ratio has been increased to 12.5:1 to take advantage of the high octane number of methanol. This vehicle was designed for German domestic conditions and has no emission control equipment.

3/ FUEL CHARACTERISTICS

Some basic properties of pure methanol and typical unleaded gasoline are given in Table 2. The actual 'methanol' used in the tests contains a proportion of higher alcohols added to simulate the composition of a fuel grade methanol or 'methyl fuel' which might be made in the future in large-scale plants for exclusive fuel use. This expected composition is necessarily somewhat hypothetical since no such plants have yet been built; however, based on the forecasts of a catalyst manufacturer and process developer [8], the following composition has been adopted.

Methanol	90%
Ethanol	2%
n-propanol	3%
iso-butanol	5%

In this report, the word 'methanol' is used to include 'methyl fuel' of the above composition.

The higher alcohols in 'methyl fuel' have some co-solvency property -- i.e., they increase the stability of methanol gasoline mixtures in the presence of water contamination. However, rather larger proportions of higher alcohols would probably be needed to ensure adequate stability under field conditions. The present investigation was not designed to examine this problem -- the fuel mixtures were prepared batchwise in drums with precautions against water ingress -- consequently, these extra higher amounts of co-solvents were not used.

The base fuel was commercially supplied unleaded gasoline and has been characterized with respect to vapour pressure, boiling range and component composition (Appendix D). Blends were made with 10% methanol (M10) and 15% methanol (M15). The addition of methanol raises the vapour pressure by 15 to 20 kPa and the distillation curve is changed. This results in a fuel with characteristics different from the normal specifications and this could be expected to cause problems in certain evaluations such as hot start (vapour-lock) and evaporative emissions. Neither of these were of concern in the present study.

Appendix E gives details of the calculations of the energy content of the base gasoline, methyl fuel and the methyl fuel/isopentane fuel mixture (M90) used with the VW Golf.

Table 2/ Some Physical Properites of Methanol and Unleaded Gasoline

PROPERTIES	METHANOL	UNLEADED GASOLINE
Specific Gravity	0.796	0.72 - 0.78
Boiling Point	65°C	27 - 225°C
Flash Point	11°C	-42°C
Flammability Limits		
By Volume		
Lower	6.7%	1.4%
Upper	36.0%	7.6%
Lower Heating Value (MJ/kg)	19.9	~44
Latent Heat (MJ/kg)	1.17	0.35
Air/Fuel Ratio (WT/WT)	6.45	14.2 - 14.8
Research Octane No.	~110	93 - 94
Motor Octane No.	~90	84 - 85
Reid Vapour Pressure (kPa)	32	55 - 90

4/ EXPERIMENTAL TECHNIQUES

4.1/ Chassis Dynamometer Facility

The chassis dynamometer was a Clayton ECE50 with adjustable inertia weights ranging up to 4000 lbs in 250-lb increments, a water-brake power absorption unit ranging up to 40 H.P. and a Constant Volume Sampling system (CVS) for analysis of the mandated emissions -- hydrocarbons (unburnt fuel), carbon monoxide, and nitrogen oxides. Carbon dioxide was also measured for the calculation of fuel consumption. In addition, total aldehydes were analysed as likely byproducts of alcohol combustion using the MBTH method (Appendix A).

4.1.1/ Exhaust Emissions

The exhaust emissions of hydrocarbons (HC), carbon monoxide (CO) and nitrogen oxides (NO_x) were measured by the 1974 Transport Canada Vehicle Emission Test procedures [9] which are based on EPA procedures. Initially the vehicle is preconditioned and left standing for at least 12 h. The test then consists of engine start up and vehicle operation on the chassis dynamometer through a specific driving schedule comprising a cold start cycle and a hot start cycle, each adding up to a distance of 12 km. A proportion of the diluted exhaust emissions is collected continuously, using a Horiba Model 20 Constant Volume Sampler into a separate sample bag for each cycle. The hydrocarbon concentration is measured by the flame ionization detector (Horiba Model OPE-405), the carbon monoxide and carbon dioxide were measured by an nondispersive infrared (NDIR) analyser (Horiba Model 105), and the nitrogen oxides were measured by a chemiluminescent analyser manufactured by Thermo Electron Corp. The relevant emission standards are as follows [10, 11]:

Table 3/ Light-Duty Vehicle Exhaust Emission Standards

	Hydrocarbons (HC)	Carbon Monoxide (CO)	Nitrogen Oxides (NO_x)
Canada (to 1985)	2.0	25	3.1 g/mile
U.S. (1980)	0.41	7	2.0 g/mile
California (1980)	0.41	9	1.0 g/mile

4.1.2/ Fuel Consumption

Fuel consumption was calculated using the method of Reference 12. Using the emission data and a carbon balance calculation based on the known fuel composition, the urban, highway and combined fuel economy of the test vehicles were calculated and expressed in L/100 km. Adaptations were made to the calculation procedure to take account of the different energy content and carbon hydrogen ratios of methanol-containing fuels, Appendix G.

4.1.3/ Constant Speed Fuel Consumption

The vehicle was also tested on the dynamometer at a number of constant speed settings (113, 97, 80, 64, 48, and 32 km/h) for a total distance of 1.6 km at each speed. The volumetric fuel consumption was measured directly by a precision fuel meter (Fluidyne Model 1250) and the time for each trip was recorded. The volume of fuel was then corrected to standard conditions and the fuel consumption was calculated. These values were compared to similar measurements made on the road and used as a basis for the determination of road load to be used to set the dynamometer power absorption unit.

4.1.4/ Driveability

Driveability is a measure of the vehicle's handling and performance as perceived by the driver and it includes starting behaviour, stalling, hesitation, irregular running, and behaviour under acceleration. Formal driveability tests have been developed over a number of years by the Co-ordination Research Council (CRC) in the US in which the performance of fleets of vehicles is rated subjectively by trained experienced drivers under controlled conditions on a test track; results are generally expressed as a Total Weighted Demerits (TWD) score for a prescribed sequence of manoeuvres. CRC have also investigated a technique of evaluating performance objectively by means of instrumentation, recording engine data with the vehicle on a chassis dynamometer [13].

When a large number of vehicles have to be tested and the test facilities and trained personnel are available, the subjective method is preferable. In the present instance, however, with very few vehicles and without access to a test track, the instrument method was used.

The sequence of test manoeuvers was adapted from that described in Reference 13. During each test, the time required to start the engine and the number of stalls was recorded. Various operating malfunctions such as hesitation, stumble, surge, idle roughness, and backfire were rated subjectively by the driver and objectively by analysing the analog records of the engine rpm, vacuum, throttle position and engine vibration in each manoeuvre. The absolute scores are not equivalent to the TWD's in the CRC subjective tests since instruments detect a greater number of faults than drivers would. However, the scores do indicate the comparative driveability of the vehicles under different conditions. Further details are given in Appendix B.

4.2/ Instrumentation

The test cars were instrumented to provide continuous chart recordings of the throttle position, engine speed, intake manifold vacuum, car speed and engine vibration. In addition, the cars were equipped with the following visual driver aids -- vacuum gauge, r.p.m. gauge, digital speedometer, and digital distance recorder. The instrumentation consists of the following:

- transducers, which provide a basic signal proportional to the quantity to be measured;
- signal conditioning circuits, which modulate the basic signals and transform them to the desired output voltages; and
- multichannel tape recording system.

4.2.1/ Transducers

The throttle position was recorded by a linear displacement transducer (HP series 7 DCDT) which was connected to the throttle linkage. The engine rpm signal was obtained using a magnetic sensor transducer (AIRPAX Model 1-0032); this non-contact transducer detects the motion of the flywheel teeth and converts it into electrical output. The manifold vacuum was measured with a pressure transducer (National Semiconductor LX 1702 GB). The car speed was measured with a speed transducer (Motorcraft Model D4AF-9E31), which connected to the speedometer cable, and the engine vibration was measured with a displacement transducer.

4.2.2/ Signal Conditioning and Output

The signals from the transducers were conditioned and then modulated by the voltage control oscillator. The frequencies were then mixed into one track by the Metraplex 300 Mixer and recorded by a magnetic tape recorder (UHER 4200). This allowed the information in different channels to record on one track. The frequency modulated signals from the tape were demodulated and the d.c. components were extracted and converted to d.c. voltage output by the MPX Discriminator Model 120. The voltage output was then converted to strip chart recording using a Honeywell Model 1858 Visicorder.

4.3/ Air/Fuel Ratio

The input air/fuel ratio was determined by analysis of carbon dioxide, carbon monoxide and oxygen in the undiluted exhaust. This was performed under steady load conditions on the dynamometer with an Orsat Volumetric Gas Analyser augmented with a Polarographic Oxygen Analyser (Teledyne 320 P-4). This gave acceptable results on the lean side (excess oxygen) where the measurements mostly are for the vehicles under test [14].

An additional air/fuel ratio measurement technique became available towards the end of the project. This used the Beckman 957 Air/Fuel Ratio Analyser. This operates by diluting the incoming exhaust with a measured amount of air and then passing the mixture over a hot catalyst. Measurement of the residual oxygen content enables a calculation to be made of the original air/fuel ratio even if unknown amounts of unburnt fuel are present -- a situation that the Orsat technique does not allow for. Some air/fuel ratio measurements are given in Appendix H, Table H.34

4.4/ Engine Settings

The manufacturers' settings for the five vehicles and the measured tailpipe emissions are shown in Table 4.

Table 4/ Manufacturers' Engine Specifications of Tested Vehicles

		IDLE		IDLE EMISSIONS		2500 rpm EMISSIONS	
Vehicle	Fuel	Timing	rpm	HC ppm	CO%	HC ppm	CO%
Honda Accord	Gas	2°BTDC*	800	150	0.18	30	0.15
VW Rabbit	Gas	3°ATDC	970	60	0.65	15	0.15
Ford Fairmont	Gas	12°BTDC*	750	low	0	low	0
White/Texaco Gremlin	Gas	25°BTDC	800	Not Tested			
VW Golf**	M90	10°BTDC	900 to 1100	1200 at 1000 rpm	0.45	120	0.15

* Vacuum removed

**Specifications not available when program began. Emissions erratic (see Appendix F).

4.4.1/ Adjustments

4.4.1.1/ Gasoline Vehicles

When driveability was noticeably degraded by the use of methanol-containing fuels, experimental adjustments were made to see if driveability could be improved without degrading other aspects of the vehicles'

behaviour such as fuel consumption and emissions. These adjustments were designed to take advantage of the enhanced octane number of the fuel and consequent possible advance in timing to offset the effect of leaner combustion. Specifically, the idle timing was advanced and the combustion mixture was enriched by turning the idle mixture control screw so that, with the use of M10 and M15, carbon monoxide and hydrocarbon emissions were approximately the same as with gasoline.

The adjustments and results are shown in Table 5.

Table 5/ Engine Adjustments Performed by MTC

	M10						M15					
	IDLE				2500 rpm		IDLE				2500 rpm	
Vehicle	Timing	rpm	HC ppm	CO %	HC ppm	CO %	Timing	rpm	HC ppm	CO %	HC ppm	CO %
Honda Accord	5°BTDC	860	75	0.2	30	0.18	6°BTDC	850	200	0.2	50	0.15
VW Rabbit	0°BTDC	920	85	0.8	50	0.15	3°BTDC	900	75	0.2	50	0.15
Ford Fairmont	15°BTDC	750	25	0	20	0						

4.4.1.2/ Multifuel Vehicle

The adjustments performed on the Gremlin were concerned with the fuel injection pump and are detailed in Section 6.2.

4.4.1.3/ Methanol Engine

The adjustment performed on this vehicle was to replace the original carburetor jet with one 12% smaller in cross-sectional area to provide a nominal 12% leaner calibration.

5/ TEST SCHEDULE

The Statement of Work from the contract agreement between MTC and Transport Canada is shown in Appendix C. In summary, the vehicles, after having been run-in for at least 4000 miles, each underwent testing on the chassis dynamometer. Testing comprised EPA/Transport Canada-style emission testing, Urban and Highway fuel consumption, fuel consumption at constant speeds and cold start and hot start driveability examinations. Initially the vehicles were adjusted for operation in the fuel they were designed for, e.g., gasoline for Honda Accord, VW Rabbit, Ford Fairmont and White/Texaco Gremlin, and methanol for the VW Golf methanol car. The gasoline cars were run on gasoline and then the appropriate fuel mixtures (see Section 2). Then adjustments were made on some vehicles, as detailed in Section 4.4.1 above, when driveability on methanol fuels was sufficiently degraded that improvement was warranted. The tests were then repeated.

After this phase of dynamometer testing, the gasoline vehicles were put into road service to accumulate 6000 to 8000 miles while other vehicles were occupying the dynamometer facility. Appendix F contains details of the service history of vehicles during this period. The fuel used during this period was 10% methanol.

Finally, the vehicles underwent another schedule of dynamometer tests to re-evaluate fuel economy, emissions and driveability to determine what changes had occurred during mileage accumulation.

The White/Texaco Gremlin and the VW Golf Methanol Vehicles were not put through mileage accumulation, but instead underwent a more extensive dynamometer testing phase with different fuels (Gremlin) or with different calibrations (Golf).

6/ RESULTS

The results are presented in three sections because of the wide differences in engine characteristics. The three sections are:

- Vehicles designed exclusively for gasoline -- Honda Accord, VW Rabbit, Ford Fairmont
- Multifuel vehicle -- White/Texaco Gremlin
- Vehicles designed exclusively for methanol -- VW Golf

Figures and Tables referred to directly in the text are included at the end of this report. The data used for the Figures are given in tables included in Appendix H.

6.1/ Honda, VW Rabbit, Ford Fairmont

6.1.1/ Results

6.1.1.1/ Fuel Consumption

Fuel consumption is expressed in terms of energy to allow for the different energy densities of methanol-containing fuels compared with gasoline. In most cases the results are the means of three repeated tests. Figures 1 and 2, and Tables 6 to 8 show the variation of fuel consumption for the three vehicles.

The Honda showed a general increase in energy consumption in the urban cycle (Figure 1) in moving from gasoline to M15 when the engine was set normally as for gasoline. The results for M10 and M15 were not fully consistent but only a single measurement for M15 was performed. The increase is due to the leanward shift in air/fuel ratio caused by the lower energy content of the mixtures which is also accompanied by an increase in unburnt fuel emissions (see Figure 3). After engine readjustment according to Section 4.4, the energy consumption was constant within the test accuracy for gasoline, M10 and M15 and this holds true in the repeat tests after mileage accumulation.

The Honda was the first vehicle to be tested on the new MTC Dynamometer Facility and the Highway Cycle mode was not operational in the beginning,

so that the highway figures for the normally adjusted vehicle are not available. However, when the Highway Cycle was performed for the re-adjusted vehicle, energy consumption was improved slightly with M15 over gasoline. After mileage accumulation, highway energy consumption increased about 4% in going from gasoline to M15.

The VW Rabbit showed a small improvement in energy consumption on the urban cycle when changing from gasoline to M10 and M15, as shown in Figure 1. Re-adjustment was not strictly necessary as the driveability was still acceptable. However, to test the effect, re-adjustment was carried out according to Section 4.4; energy consumption was lowered slightly with gasoline and showed further slight improvements with M10 and M15. These results are repeated almost exactly after mileage accumulation except that the consumption with M15 was lower than before.

The highway energy consumption follows the urban data closely, showing an improvement after re-adjustment and an improvement with transition to methanol-containing fuels.

For the Fairmont, the energy consumption values are shown in Figures 1, and 2. As in the case of the VW Rabbit, driveability was satisfactory with all fuels, and no re-adjustment was necessary. However, an advance adjustment was made to test the effect in one case, M10, and an improvement in fuel consumption was noted. After mileage accumulation, the vehicle was tested at its original gasoline setting for all the fuels. The first energy consumption result for gasoline was rather low compared with the later results. Apart from this, the trend was towards decreasing energy consumption with transition towards higher methanol concentration. Overall, there is reasonable consistency in the consumption between the beginning and the end -- a period exceeding one year. Results for the combined fuel consumption for M10 and M15 were within 2.5% and 1%, respectively.

6.1.1.2/ Emissions

Vehicle emissions are shown in Figures 3 to 5 and Tables 6 to 8. With the Honda, emissions of hydrocarbons (unburnt fuel, HC) were increased substantially and emissions of carbon monoxide (CO) were increased a little in a normally set-up engine as the fuel ranged from gasoline to M15.

Nitrogen oxides emissions (NO_x) for gasoline and M15 were the same and the high value in M10 was probably anomalous. With re-adjustment for increased spark advance, all emissions were reduced and the trends were changed in that emissions were lowered in the transition from gasoline to M15. After mileage accumulation, emissions performance was improved for HC and CO with the same trends (with timing adjustments) as before. However, the emissions of NO_x were increased after mileage accumulation.

With the VW Rabbit, HCs were distinctly increased with the transition from gasoline to M15 in a normally set-up engine. CO was slightly decreased and NO_x was substantially lowered during this transition. Engine re-adjustment had little effect on these trends. After mileage accumulation, the trends were the same for M10. For M15, however, HCs were much improved while CO was worse.

The Ford Fairmont showed slight decreases in HC and CO and slight increases in NO_x oxides in the transition from gasoline to M15 in a normally set-up engine. Re-adjustment had little effect on the emission levels with M10. After mileage accumulation, NO_x emissions increased while CO and HC were more scattered between the different fuels with a general tendency to increase. The trends of emissions with fuel composition moving from gasoline to M15 were the same as before -- CO and HC were generally diminished and NO_x always increased.

6.1.1.3/ Driveability

Driveability is shown in Figures 6 and 7. The Honda Accord was degraded strongly in driveability, particularly during cold starting, in the transition from gasoline to M15, necessitating re-adjustment for acceptable performance. Re-adjustment restored acceptable cold start driveability for M10, but performance with M15 was still degraded about 60%. After mileage accumulation, cold start driveability declined between 15 and 30% for the three fuels with the same trend as before in going from gasoline to M15. Hot start driveability was approximately 100% worse with methanol-containing fuels but the re-adjustment procedure resulted in satisfactory performance.

The VW Rabbit showed no degradation in cold start driveability in the transition from gasoline to M15 when the vehicle was normally set. No re-adjustment was therefore needed for driveability improvement; nevertheless, when timing was advanced to check the effect, some improvement did take place. After mileage accumulation, however, slight degradation occured. Appendix F details some of the faults occurring during this period which, though rectified as well as possible, may have caused the fuel delivery system to deteriorate.

With the Ford Fairmont, cold and hot driveability was relatively unchanged when switching from gasoline through to M15, reflecting the automatic feedback control of carburetion. No change was noted when a re-adjustment was made and the vehicle tested for M10 fuel. Driveability demerits for cold starting covered a somewhat larger range between gasoline and M15 after mileage accumulation than before but the deterioration was not severe. With hot start tests, the behaviour was unaffected by fuel composition within the error of the test.

6.1.2/ Discussion

6.1.2.1/ Honda Accord

The Honda was significantly worse in driveability when using methanol-containing fuels, and some readjustment was necessary to restore acceptable driving behaviour. This is interpreted as being due to the particularly lean calibration of this engine (A/F 18.2, λ = 1.24) and the fact that the use of M15 sends the engine still leaner (λ = 1.33). The stratified charge concept enables the initial extreme calibration to be handled with gasoline but it is in a region of considerable sensitivity. Because of the inevitable cylinder-to-cylinder variability in mixture composition, some cylinders reach the misfire limit with lower energy density methanol-containing fuels leading to poor driveability.

The increase in CO emissions observed with this engine using methanol-containing fuels has been reported elsewhere, e.g., [15]. This is not expected in a conventional engine, the typical behaviour of which is shown in Figure 8, where CO tends to decrease to negligible levels as the engine is run leaner. In the Honda two-carburetor engine, however, it is expected that the prechamber will be supplied with a richer fuel mixture when methanol fuel mixtures are used compared with gasoline, to

compensate for the loss in power occasioned by the less energy-dense fuels. The auxiliary carburetor feeding the prechamber supplies an increasing proportion of the total fuel used as the power output increases. The richer mixture in the prechamber would produce higher concentrations of CO and HC due to incomplete combustion. However, if the overall stoichiometry in the rest of the cylinder space is in the misfire region, these components are not consistantly oxidized -- thus causing an increase in overall emissions. When a homogenous charge conventional engine misfires, however, only unburnt fuel (HC) increases, not CO.

The resultant emissions with M10 and M15 would cause the vehicle to fail the Canadian Standard on HC so that for this reason as well, re-adjustment was needed. The effect of re-adjustment for M10 rendered that fuel acceptable with respect to emissions and driveability while achieving the same energy efficiency as before. Re-adjustment for M15 rendered that fuel satisfactory for emission and energy efficiency but only marginally satisfactory for driveability. The behaviour of a vehicle calibrated for M10 and running on, say, gasoline, has not been examined but it is likely that a compromise setting could be reached. The conclusion is that M10 is a satisfactory fuel for this vehicle when a re-adjustment is made but M15 is outside the range. The long-term durability of fuel line components with exposure to methanol-containing fuels does not seem bad. A record of some driveability problems observed and rectified during the mileage accumulation period is given in Appendix F. No degradation of plastic components was observed but there were some problems caused by dirt blockage, possibly resulting from metallic corrosion.

6.1.2.2/ VW Rabbit

This vehicle when normally set for gasoline performed equally as well with M10 with respect to emissions and driveability. With M15, driveability was still as good as before but the HC emissions exceeded the Canadian Standard limit. No re-adjustments were necessary for these fuels for driveability reasons but, when applied, some improvement in driveability was obtained for M10; however, the NO_x was right on the Canadian Standard limit. With M15, the behaviour was similar but the HCs were not improved. In both cases there was a slight increase in energy efficiency.

The explanation of the tolerance of the VW engine to fuels of different energy content lies with the properties of the fuel injection system and the air/fuel ratio setting. The setting (~1.0) is far from the lean combustion limit and the port injection applied to the four cylinders minimizes the cylinder-to-cylinder variation in air/fuel ratio that is characteristic of carbureted engines and which leads to misfiring. In experiments described in Appendix F, before the vehicle entered the test program described here, much higher concentrations of methanol were used, up to M50, corresponding to a 25% shift in λ, and satisfactory performance was observed without re-adjustments, at least up to M40.

The long-term durability of the fuel system components of this vehicle in methanol-containing fuels is suspect. Appendix F indicates some of the malfunctions occasioned by component degradation and indicates that the system is more vulnerable than the fuel system of the Honda. However, this vehicle was exposed to higher levels than 15% methanol during early testing and this may have exacerbated the problem.

6.1.2.3/ Ford Fairmont

This vehicle performed satisfactorily at the factory setting when run with M10 and M15 with emissions and driveability little changed. This is expected for an engine where the air/fuel ratio is automatically adjusted to the stoichiometric value by the feedback carburetor. Apart from the first result obtained for gasoline, a decrease in energy consumption occurred in the transition to M15, even though the equivalence ratio changed very little because of the self-adjusting carburetor; however, a decreased energy consumption was obtained for M10 when a re-adjustment was made.

This vehicle, designed for the California Emission Standards (0.41 g/mi HC, 9.0 g/mi CO, 1.0 g/mi NO_x) showed considerably reduced emissions compared to the Honda and VW, which have no catalysts. The vehicle met the emission standards on all fuels but the NO_x levels were at the borderline (given the variance of the data) for M10 and M15. Timing re-adjustment for M10 fuel caused a slight increase in HC which is also at the borderline of the California standard. After mileage accumulation, NO_x emissions increased consistently for all fuels and were then above the California standard but still below the U.S. and Canadian standards.

6.1.3/ Conclusions

The Honda and Volkswagen, when adjusted according to manufacturers' specifications as for gasoline, were affected in performance when used with methanol-containing fuels due mainly to the shift in air/fuel ratio. With M10, the changes were within acceptable bounds with respect to emissions and driveability though a timing advance for the Honda was advantageous. When M15 was used, performance sometimes fell outside the range of acceptability because of emissions or driveability.

The Ford Fairmont with its self-adjusting carburetor system successfully compensated for the different fuel composition and could be used with mixtures up to M15.

Some deterioration of components has been observed due to exposure to the methanol-containing fuels. This is particularly noticeable for the VW -- although it has been exposed to higher levels of methanol than the other vehicles. Component degradation is potentially the most serious problem in using methanol fuels in vehicles designed for gasoline.

6.2/ White/Texaco Gremlin

This engine has been designed for gasoline as a base fuel with a view to operation with other hydrocarbon fuels. Unlike conventional engines, the power output depends directly on the capacity of the high-pressure direct injection fuel pump, and this has been sized for hydrocarbons. Even so, the power available on gasoline was low, as seen from the 0 to 80 km/h acceleration time (13.2 s) with the original factory-assembled fuel pump. As the engine is, by design, tolerant of a wide variety of fuels without octane or cetane requirement, tests were conducted on gasoline, 100% methanol (M100) or 100% ethanol (E100). Later, 70% methanol in gasoline (M70) was used to raise the energy density of the fuel.

With M100, the power was reduced to about half in proportion to the energy density of the fuel. This meant that certain parts of the drive cycle could not properly be reproduced as the top speed and acceleration were inadequate.

In order to protect the fuel system from the possible degradative effects of alcohol exposure, the full EPA/TC test procedure with overnight cold soak was not used at first. Instead, the following test cycle (designated DYN.9) derived from it was used. The terms Bag 1, Cold Start, etc., refer to the usual EPA/TC sequences [9].

Warm-Up Cycle			Collection Cycle	
Bag 1 Cold Transient	Bag 2 Stabilized	Hot Soak (Engine off)	Bag 1 Transient	Bag 2 Stabilized

After starting and warming up on gasoline, the recirculating fuel system was switched to methanol during the Hot Soak period. During the next transient phase (Bag 1), the fuel was flushed through the system so that the following stabilized cycle (Bag 2) could be run on straight methanol. At the end of this sequence, the system was flushed out again with gasoline.

6.2.1/ Results with Original Fuel Pump

The standard EPA/TC emissions and fuel consumption figures with gasoline are shown in Table 9; and the DYN.9 values for gasoline, methanol and ethanol are shown in Table 10.

The vehicle emissions on gasoline passed the Canadian Standard and the U.S. standard till 1979, but were above the U.S. 1980 standard for HC. The use of methanol reduced HC (UBF) somewhat but, if judged by the proportionate effect it has in the DYN.9 test, UBF would still not be low enough to clear the 1980 standard (0.41 g/mi).

The energy efficiency with gasoline and methanol was about the same but that for ethanol appeared greater by about 5%.

6.2.2/ Results with Rebuilt Fuel Pump

As the fuel pump had not been designed to supply the doubled fuel flow necessary for methanol, engine power was much reduced giving, for example, a 0 to 80 km/h acceleration time of 29.1 s compared to 13.2 s for gasoline. To increase available power, an enlarged pump was devised by boring out one of the existing standard ones, (Roosa Master DB2) to

increase volume delivery by a nominal 30%.* This did not work satisfactorily because of instability in the pressure control system of the pump leading to engine surging. It is obvious that only a properly redesigned pump with enlarged capacity will be suitable.

When the original pump was reassembled and after an interval during which the vehicle was under test by another group, the vehicle was retested by MTC. Due to a slight change in the disposition of the fuel line connection to the new pump body, it was not possible to restore entirely the original timing setting which depends on the rotation of the pump body about the drive shaft. This may be responsible for the much-reduced power which was then obtained with methanol (43.4 s to accelerate from zero to 80 km/h compared to 14.6 s for gasoline; see Table 13). Standard EPA/TC tests were carried out this time on gasoline, M70 and M100 -- accepting the risk of component degradation. Emission results are shown for only gasoline and M70 in Table 11 as engine power with M100 was not sufficient to follow all parts of the cycle. It is seen that HC (UBF) was still excessive and actually increased for M70 where it exceeded even the U.S. 1979 standards (1.5 g/mi). Likewise, NO_x also exceeded slightly the U.S. and Canadian standards (2.0 g/mile). Significant amounts of aldehydes were also produced (~1 g/mile) even though a catalyst was present.

Results for the stabilized cycle of the DYN.9 tests for gasoline, M70 and M100 are shown in Table 12. Energy consumption was equal for gasoline and M100 and for M70 it was about 8% higher, which is doubtfully significant for the results of two tests. Emissions for gasoline and M70 were similar to the weighted emissions of the full EPA/TC tests (see Table 11) showing rather high HC, NO_x and aldehydes. With M100, these components were increased still further.

6.2.3/ Conclusions

The White/Texaco engine as a prototype is not yet optimized for operation on fuels containing less energy than hydrocarbons, even though it will run on them with identical efficiency. Emission performance with M100

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*Pump supplied and installed by G. Kandel, White Engines Inc., Canton, Ohio.

would not meet current Canadian standards on hydrocarbons (unburnt fuel), and the aldehydes seemed excessive even though no standards exist as yet for them. Engine power levels were entirely inadequate on methanol because of the low fuel pump capacity.

6.3/ VW Golf Methanol Vehicle

This vehicle is a limited production prototype imported direct from Volkswagen in Germany through the agency of Transport Canada and Canadian Methanol Canadien (CMC), Winnipeg. Unlike other vehicles tested, which have been designed or made suitable for Canadian conditions, this vehicle is designed for German domestic conditions and has, for example, a manual choke and no emission control equipment.

After an initial running-in period of 7600 km (4750 miles) the vehicle was placed under test for fuel consumption, emissions, driveability and cold starting performance. A major problem which straight methanol vehicles have to contend with is starting and running under low temperature conditions. These problems arise from the higher latent heat required (7 times as much per equivalent combustion charge) and much lower vapour pressure compared with gasoline. The latent heat factor has been overcome in this engine by means of a water jacketed heat exchanger in the inlet manifold while the low vapour pressure is circumvented by the addition of a volatile hydrocarbon to the methanol, e.g., iso-pentane. A combination of two fuel compositions and two air/fuel ratio calibrations has been used in testing. The vehicle, as received, was first examined with M100 and with M90 (90% Methanol with 10% iso-pentane). M100 is adequate for warm weather conditions while M90 is required for low temperature starting. Since the original calibration was apparently rather rich as indicated by CO levels, the carburetor main jet was then replaced with one of smaller size (nominally 12% less area) to test the effect of leaner calibration.

6.3.1/ Low Temperature Starting

A series of tests were carried out with different fuel compositions to determine the minimum temperature at which starting was adequate.

The fuel compositions used were M100 (straight methanol), M95 (methanol with 5% iso-pentane) and M90 (methanol with 10% iso-pentane). The vehicle was parked overnight in a temperature controlled trailer and starting performance noted. Using M100, starting was unreliable below about 10°C. It should be noted that this temperature is approximately that at which the saturated vapour pressure of methanol is at its lower combustion limit (lean limit).

6.3.1.1/ M95

With the original calibration starting was obtained, on occasion, down to 0°C, but with difficulty; reliable starting was not obtained below about 5°C. Much depended on correct manual choke setting. Difficulties were caused if firing did not take place immediately on starting due probably to wetting of the spark plugs by the relatively involatile methanol.

Generally, between 5°C and 0°C, the vehicle required several priming pumps on the accelerator, and the manual choke pulled at least three-quarters out. Cranking time to obtain first firing varied between 2 s at 4°C to more than 2 min at 0°C. False starts varied in number from 1 to 20. The conclusion is that the addition of 5% iso-pentane only decreased starting temperatures by about 5°C and was not adequate to accommodate low winter temperatures.

6.3.1.2/ M90

Starting was obtained down to -20°C with varying difficulty. Initial firing took place generally within five to seven seconds but several false starts tended to occur. Thereafter, the engine sometimes missed on several cylinders for one to two minutes until even running was obtained. Three-quarters to full choke was required. The conclusion is that the addition of 10% iso-pentane enables practical if not ideal starting at least down to -20°C.

6.3.2/ Fuel Consumption

The results for EPA/TC dynamometer tests using M90 and M100 before and after adjustment are shown in Figure 9 and Table 14. Some of the same data are displayed against equivalence ratio in Figure 11. The combined fuel consumption for the standard vehicle in energy units, 2.37 MJ/km,

was 2.5% less for M90 than that previously obtained for the VW Rabbit (2.43 MJ/km), using gasoline. The vehicle and engines are identical in all important parameters except for compression ratios (Rabbit 8.1, Golf 12.5). This improvement in energy efficiency was less than the value expected (in the range 14-17% for practical engines [16] and estimated at 10-15% in Volkswagen's own development papers [17, 19]. However, these improvements apply to engines that are fully optimized with respect to A/F ratio. The Golf as originally supplied was calibrated for M100 and was therefore running rich with M90 as indicated by the high CO and HC (unburnt fuel) emissions. While running on M100 the energy efficency improvement was about 11.5% over the VW Rabbit, which is closer to expectations.

When the vehicle was leaned out, a further improvement in relative energy efficency took place, so that with M90 and M100 it was 7% and 13% better, respectively.

6.3.3/ Emissions

For the standard vehicle using M90, UBF (Figure 10) was approximately six times more than for the VW Rabbit (HC 1.4 g/mi) and would fail Canadian standards (for which, however, the vehicle was not designed). UBF is measured with a flame ionization detector calibrated for propane and no allowance is made for a different response factor for methanol (about 0.73 [18]). With M100, unburnt fuel was even higher. When the engine was leaned out, only a slight reduction of unburnt fuel was observed with that for M100 being still higher than for M90. When plotted on a equivalence ratio scale (Figure 11) it is seen that UBF was higher for M100 than M90 for a given value of λ, no doubt reflecting the poorer volatility of the former.

CO was high for M90 in the standard vehicle (34.4 g/mi) and exceeded the Canadian standard (25 g/mi). Operation with M100 reduced CO substantially. When the engine was leaned out, the CO emissions for both fuels were reduced but, for a given equivalence ratio (Figure 11), the CO was higher for M90 compared with M100.

NO_x emissions were always below the standard (3.1 g/mi) with both fuels and calibrations. Aldehydes were in the range 0.7 to 0.8 g/mi and are also included in the UBF total.

With methanol as fuel, the measured aldehydes are mostly the component formaldehyde and, in view of its high toxicity (maximum average level of exposure over an 8 h period should not exceed 3 ppm), the measured values must be considered excessive. It is certain, however, that the oxidizable emissions (UBF, CO and aldehydes) would be much reduced with standard emission control techniques with an oxidation catalyst. This is illustrated by References 20 and 21, where measurements were made on methanol vehicles with and without catalysts. The results can be expressed in the form of percentages of emissions removed, thus:

Emission	Reference 20		Reference 21
	Noble Metal Catalyst	Base Metal Catalyst	3-way & Oxidation Catalyst
UBF	96%	97%	91%
CO	85%	96%	94%
Formaldehyde	91%	99%	88%

The conclusion is that conventional emissions reduction techniques applied to the vehicle would enable a methanol vehicle to meet the Canadian Standards adequately with the mandated emissions and would reduce aldehydes to acceptably low levels.

6.3.4/ Driveability

As seen from Figure 12, cold start driveability was distinctly worse than for gasoline-fueled vehicles. Assuming 150 demerits for a normal vehicle, the Golf is about 60% worse on M90 and a 100% worse for M100 for the standard vehicle. This was caused by persistent stalling and erratic running during warm-up. With the leaner vehicle, some improvement was obtained. Hot start driveability was satisfactory on all fuels.

Likewise, acceleration was completely satisfactory -- ranging from 12 s, 0 - 96 km/h, for M90 on the standard engine to 14 s with M100 on the lean engine. The figure for the Rabbit using gasoline was 13.2 s.

6.3.5/ Conclusions

The overall performance of the Golf vehicle is satisfactory compared to the equivalent gasoline vehicle, the VW Rabbit, and the energy efficiency is improved. This energy efficiency can probably be improved still further by more lean calibration though this benefit is mostly seen only in the highway portion of the combined fuel consumption figure. The greatest problem associated with the vehicle is unusually high unburnt fuel emissions and poor cold start driveability, both deriving from the poorer volatility and increased evaporative heat required for methanol-containing fuels. Emissions could possibly be mitigated by various control techniques such as an oxidation catalyst. Also, because methanol vapour is biodegradable and not involved in smog formation, higher levels may be more tolerable than equivalent levels of hydrocarbons. Achieving cold start behaviour comparable with accepted North American standards may, however, require further developmental work.

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- "Effect of Water on Combustion Characterisitcs of Alcohol Fuels" S. Koda, M. Nakamura, K. Oda, T. Hirano and K. Akita; Vol. 2, 69.

- "Combustion and Exhaust Emission Characteristics of a Methanol Fueled Spark Ingition Engine," H.B. Mathur, M.K. Gajendra Babu and K. Subba Reddi; Vol. 2, 93.

- "Combustion Characteristics of a Methanol Fueled SI Engine," S. Muranaka, Y. Nakajima, Y. Takagi and K. Ohkawa; Vol. 2, 101.

- "In-Cylinder Charge Non-Homogeneity and Cyclic Combustion Variations in an SI Engine with Alcohol Fuels," B.P. Pundir, V.A. Zvonov and C.P. Gupta; Vol. 2, 142.

- "Burning Rates in Alcohol Fueled SI Engines -- Comparison of Reynolds Parameter and Eddy Entrainment Models," K. Subba Rao, V. Ganesan, K.V. Gopalakrishnan and B.S. Murthy; Vol. 2, 176.

- "An Analytical Investigation of NO_x Control Techniques for Methanol Fuelled Spark Ingition Engines," L.H. Browning and L.A. Argenbright; Vol. 3, 133.

- "Methylnitrite Formation in Exhaust Gases Emitted from Methanol Fueled SI Engines," K. Ito, T. Yano and F. Takahashi; Vol. 3, 171.

- "An Investigation into the Reliability of Aldehyde Level Measurements or Emission Testing in Alcohol Fueled Cars," D.C. Kappatos and J. Coe; Vol. 3, 187.

[16] "A Thermodynamic Simulation Model for a Methanol Fueled Spark Ignition Engine," H.B. Mathur, M.K. Gajendra Babu and K. Subba Reddi; SAE 830333

[17] "Energy Efficiency of Oxygenates from their Production to their Engine Use," A.W. Preuss, SAE 830384.

Engine Wear and Component Degradation with Methanol-Containing Fuels

[18] "Corrosion Considerations in Design of Automotive Fuel Systems," D.J. Bologna and H.T. Page, SAE 780920.

[19] "The Effect of Gasohol and Alcohols on Elastomeric Materials," C.W. Cheng, International Packings Corp. Paper preented to Detroit Rubber Group Meeting, Detroit, Michigan, October 18, 1979.

[20] "A Report on Viton in Automotive Fuel Systems," 1980, Published by E.I. DuPont de Nemours & Co. (Elastomers Divison) Wilmington, Delaware.

[21] "Effects of Mixtures of Gasoline with Methanol and Enthanol on Automotive Elastomers," I.A. Abu-Isa, SAE 800786.

[22] "The Effect of Alcohol Fuels and Fully Formulated Lubricants on Engine Wear," H.W. Marback Jr., E.A. Frame, E.C. Owens and D.W. Naegeli, SAE 811199.

[23] "The Mechanisms Leading to Increased Cylinder Bore and Ring Wear in Methanol Fuel S-I Engines," T.W. Ryan III, D.W. Naegeli, E.C. Owens, H.W. Marbach and J.G. Barbee, SAE 811200.

[24] "Wear Studies on an Automotive Gasoline Engine Using Methanol Gasoline Blends -- A Study of the Effects of Variables," P.C. Nautiyal, Mahi Pal and V.A. Zvonow; SAE 821186.

[25] "Evaluation of Fuel Additives to Reduce Engine and Fuel System Material problems with Methanol-Gasoline Blends," C.F. Rodriguez and J.P. Cuellar, SRI. Reported to DOE Automotive Technology Development Contractors Co-ordination Meeting, Dearborn, Michigan, October 1982.

[26] From the Proceedings of the Fifth International Alcohol Fuel Technology Symposium; Auckland, New Zealand, May 1982:

- "Evaluation of Lubricants for Methanol-Fueled Engines," G.K. Chui, E.T. King and F. Pedrys; Vol.2, 411.

- "Lubrication of Spark Ignition Engines Running on Alcohol Containing Fuels," H. Krumm, W. Foerster, A.A. Reglitzky, R.C. Coy and A.G. Bell; Vol. 2, 427.

- "Crankcase Oil Development For Alcohol Fueled Engines," D.H.T. Millard, B.J. Howlett and S. Chaibongsai; Vol. 2, 435.

- "Approaches to Controlling Wear in Alcohol-Fueled Engines," E.C. Owens, D.W. Naegeli, H.W. Marbach, T.W. Ryan III and E.A. Frame; Vol. 2, 443.

- "Testing of Fuel System Materials for Alcohol Fueled Engines," W.D. Tallent, P.C. Killgoar Jr., R.R. Wiggle, G.J. Chui, E.A. Cox, E.A. Styloglou, R.A. Pett and M.A. Lemieux; Vol. 2, 451.

- "Motor Oil Development for Methanol Engines," H.C. Wolff, D. Smith and P. Fry; Vol. 2, 467.

[27] "Test Stand Evaluations of Commercial Lubricants with Methanol and Tertiary Butyl Alcohol Blends," J.M. DeJovine, D.A. Drake and M.A. Mays; SAE 830242.

Table 6/ Honda Accord: Energy Consumption and Emissions

	BEFORE MILEAGE ACCUMULATION						AFTER MILEAGE ACCUMLATION		
	BEFORE ENGINE ADJ			AFTER ENGINE ADJ			AFTER ENGINE ADJ		
MJ/km	URBAN	HYW	COMBINED	URBAN	HYW	COMBINED	URBAN	HYW	COMBINED
GAS	2.64	--	--	2.72	1.97	2.38	2.70	1.99	2.38
M10	2.99	--	--	2.73	--	--	2.72	2.05	2.42
M15	2.78	--	--	2.68	1.90	2.27	2.68	2.07	2.40

	BEFORE MILEAGE ACCUMULATION						AFTER MILEAGE ACCUMLATION		
	BEFORE ENGINE ADJ			AFTER ENGINE ADJ			AFTER ENGINE ADJ		
g/mile	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
GAS	1.16	7.41	1.88	1.28	8.60	1.59	0.96	8.57	1.80
M10	3.41	10.0	3.36	1.73	6.79	1.27	0.52	4.41	1.64
M15	3.84	8.59	1.74	1.00	5.88	1.18	0.67	5.18	1.40

Table 7/ VW Rabbit: Energy Consumption and Emissions

	BEFORE MILEAGE ACCUMULATION						AFTER MILEAGE ACCUMLATION		
	BEFORE ENGINE ADJ			AFTER ENGINE ADJ			AFTER ENGINE ADJ		
MJ/km	URBAN	HYW	COMBINED	URBAN	HYW	COMBINED	URBAN	HYW	COMBINED
GAS	2.88	2.13	2.55	2.79	2.00	2.43	2.80	2.00	2.44
M10	2.86	2.04	2.49	2.78	1.97	2.42	2.78	1.96	2.41
M15	2.80	1.99	2.44	2.74	1.93	2.38	2.65	1.81	2.27

	BEFORE MILEAGE ACCUMULATION						AFTER MILEAGE ACCUMLATION		
	BEFORE ENGINE ADJ			AFTER ENGINE ADJ			AFTER ENGINE ADJ		
g/mile	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
GAS	1.29	5.33	2.80	1.37	7.16	2.60	1.39	16.20	2.49
M10	1.35	6.20	2.21	1.50	4.93	3.13	1.30	8.19	3.19
M15	2.98	3.64	1.94	3.12	3.77	2.38	1.57	5.58	2.20

Table 8/ Ford Fairmont Energy Consumption (MJ/km) and Emissions

	BEFORE MILEAGE ACCUMULATION						AFTER MILEAGE ACCUMLATION		
	BEFORE ENGINE ADJ			AFTER ENGINE ADJ			BEFORE ENGINE ADJ		
MJ/km	URBAN	HYW	COMBINED	URBAN	HYW	COMBINED	URBAN	HYW	COMBINED
GAS	3.57	2.67	3.17	--	--	--	3.75	2.92	3.32
M10	3.81	2.95	3.42	3.55	2.78	3.18	3.67	2.95	3.35
M15	3.66	2.86	3.30	--	--	--	3.58	2.85	3.25

	BEFORE MILEAGE ACCUMULATION						AFTER MILEAGE ACCUMLATION		
	BEFORE ENGINE ADJ			AFTER ENGINE ADJ			AFTER ENGINE ADJ		
g/mile	HC	CO	NO_x	HC	CO	NO_x	HC	CO	NO_x
GAS	0.41	4.53	0.79	--	--	--	0.62	7.33	1.50
M10	0.326	4.23	1.15	0.46	4.17	1.14	0.12	4.06	1.75
M15	0.25	2.60	1.27	--	--	--	0.41	3.80	2.11

TABLE 9/ Gremlin Exhaust Emissions From Each Bag (EPA Cycle)

FUEL: Gasoline S.G. 0.734

g/mile	HC	CO	NO_X
BAG 1	1.02 (±0.25)*	1.35 (±0.31)	2.17 (±0.34)
BAG 2	1.57 (±0.49)	1.13 (±0.47)	2.12 (±0.34)
BAG 3	0.79 (±0.25)	1.03 (±0.33)	2.15 (±0.41)
WEIGHTED EMISSIONS	1.24 (±0.33)	1.15 (±0.35)	2.14 (±0.38)
NO. OF TESTS	6	6	6

GREMLIN EPA FUEL CONSUMPTION (6 TESTS)

URBAN	7.65 ±(0.24) L/100 km
HWY.	5.93 ±(0.68) L/100 km
COMBINED	6.90 ±(0.49) L/100 km

Note: -- Data in brackets indicate 90% confidence level.

Table 10/ Gremlin Exhaust Emissions and Fuel Consumption From Stabilized Bag (EPA/TC CYCLE) DYN 9 With Standard Fuel Injection Pump

FUEL	VOLUMETRIC (L/100 km)	ENERGY (MJ/km)	CO	HC	NO_X	NO. OF
			(g/mile)			TESTS
GAS	7.51	2.40	1.27	1.02	2.37	3
METHANOL	14.40	2.37	0.71	0.84	2.22	2
ETHANOL	10.95	2.27	0.79	1.11	2.45	1

Table 11/ White/Texaco Gremlin, Standard Fuel Consumption and Emissions and Emissions, Reassembled Pump

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.17	0.35	0.17	2
CO	1.02	0.29	0.14	2
NOx	2.39	0.10	0.05	2
HCHO	0.85	0.36	0.18	2

M70	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.93	0.18	0.09	2
CO	1.35	0.29	0.14	2
NOx	2.17	0.65	0.32	2
HCHO	1.17	0.32	0.16	2

Fuel Economy Measured by EPA Driving Cycle

	GAS						M70					
Before AdJ	URBAN		HWY		COMBINED		URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	8.12	2.50	6.27	1.93	7.29	2.24	10.95	2.29	8.15	1.70	9.69	2.03
90% Confid- ence	0.80	0.17	0.27	0.06	0.55	0.12	1.31	0.27	1.90	0.40	1.57	0.33
STD. DEV.	0.39	0.08	0.13	0.03	0.27	0.06	0.64	0.13	0.93	0.19	0.77	0.16
No. of Tests	2		2				2		2			

Table 12/ Gremlin Exhaust Emissions and Fuel Consumption From Stabilized Bag (EPA/TC Cycle) DYN.9, Reassembled Pump

FUEL	FUEL CONSUMPTION		EXHAUST EMISSIONS				
	VOLUMETRIC L/100 km)	ENERGY (MJ/km)	CO	HC	NO_x	HCHO	NO OF TESTS
			g/mile				
GAS	7.61	2.43	1.12	1.63	2.26	0.85	2
M70	12.43	2.63	1.00	1.87	2.02	1.27	2
PURE METHANOL	15.01	2.47	0.73	2.17	1.05	1.53	2

Table 13/ Acceleration Test, 0 - 50 mph

	GAS	M70	M100
TIME (SECONDS	14.6	24.3	43.4
HP at 50 mph	15.7	14.8	13.5
No. of Tests	3	3	3

Table 14/ VW Golf, Energy Consumption (MJ/km) and Emissions on M90 & M100

MJ/km	STANDARD CARBURETOR			LEAN CARBURETOR		
	URBAN	HYW	COMBINED	URBAN	HWY	COMBINED
M90	2.65	2.02	2.37	2.62	1.86	2.27
M100	2.49	1.81	2.18	2.49	1.70	2.15

g/mile	STANDARD CARBURETOR				LEAN CARBURETOR			
	HC	CO	NO_x	HCHO	HC	CO	NO_x	HCHO
M90	8.35	34.39	1.92	0.77	6.77	19.36	1.27	0.71
M100	9.08	11.39	1.08	0.82	7.85	8.83	1.06	0.68

Figure 1/ Honda/VW/Ford: TC/EPA Urban Cycle Fuel Energy Consumption; Gasoline, M10, M15

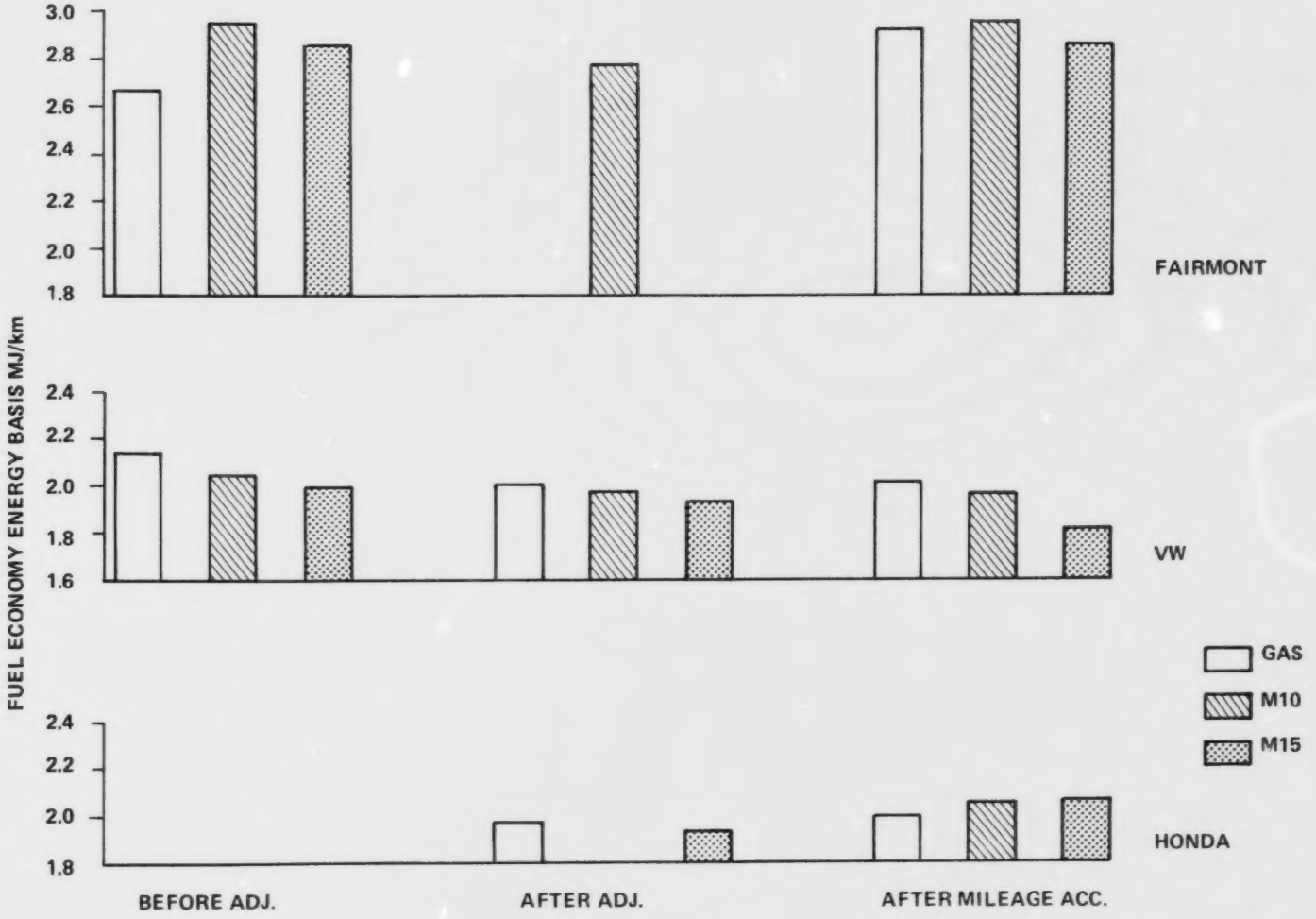

Figure 2/ Honda/VW/Ford: TC/EPA Highway Cycle Fuel Energy Consumption; Gasoline, M10, M15

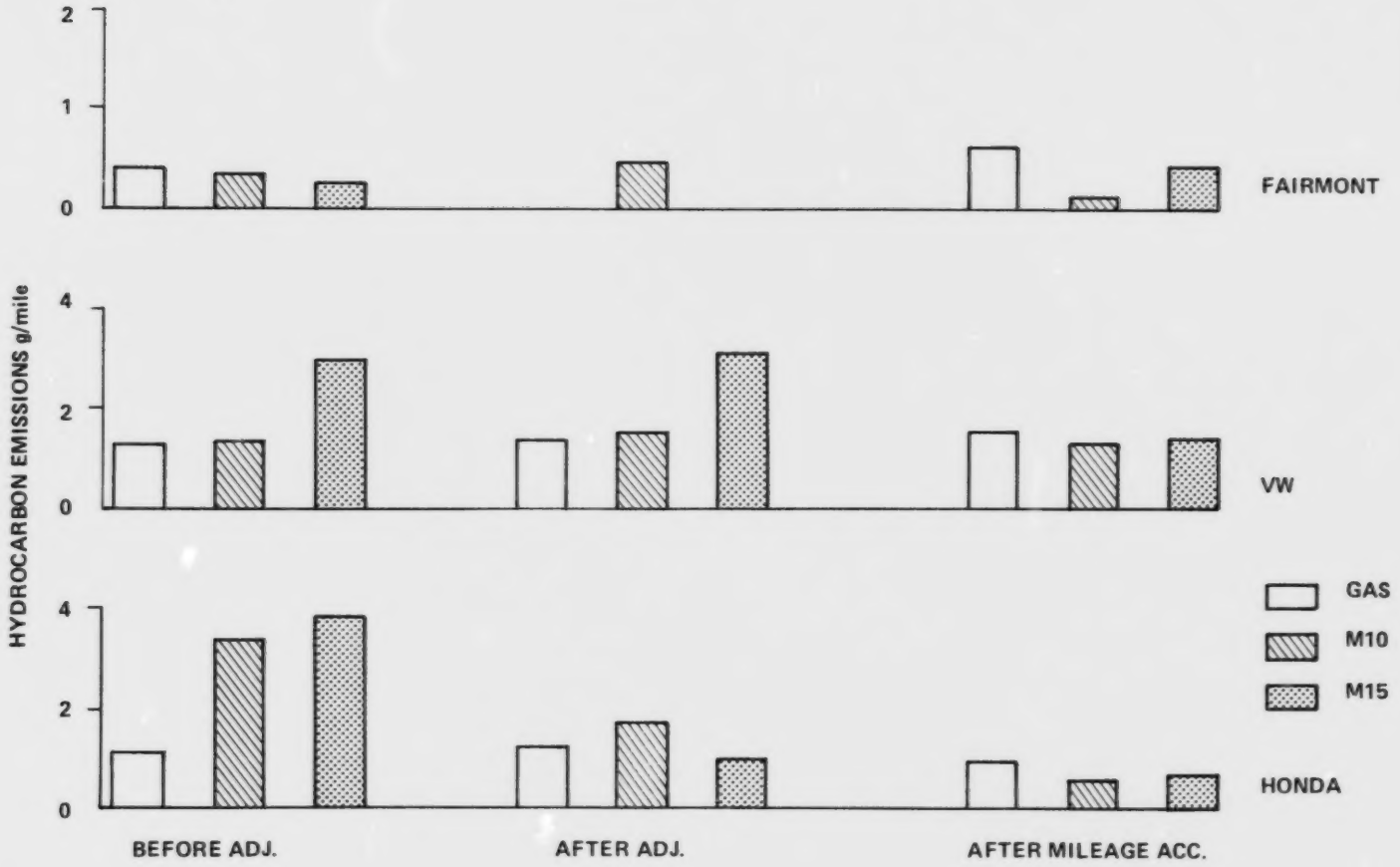

Figure 3/ Honda/VW/Ford: Emissions of Hydrocarbons; Gasoline, M10, M15

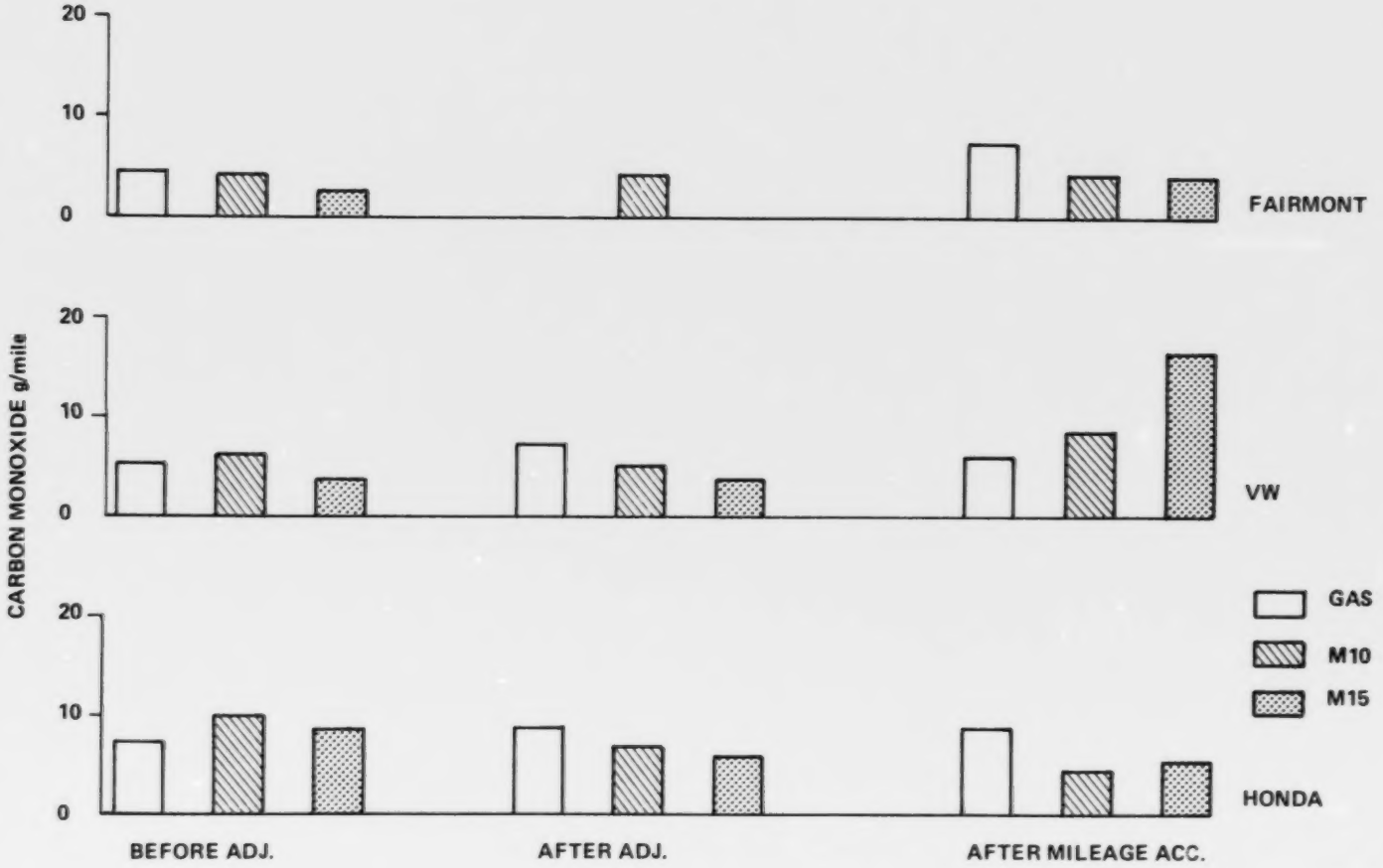

Figure 4/ Honda/VW/Ford: Emissions of Carbon Monoxide; Gasoline, M10, M15

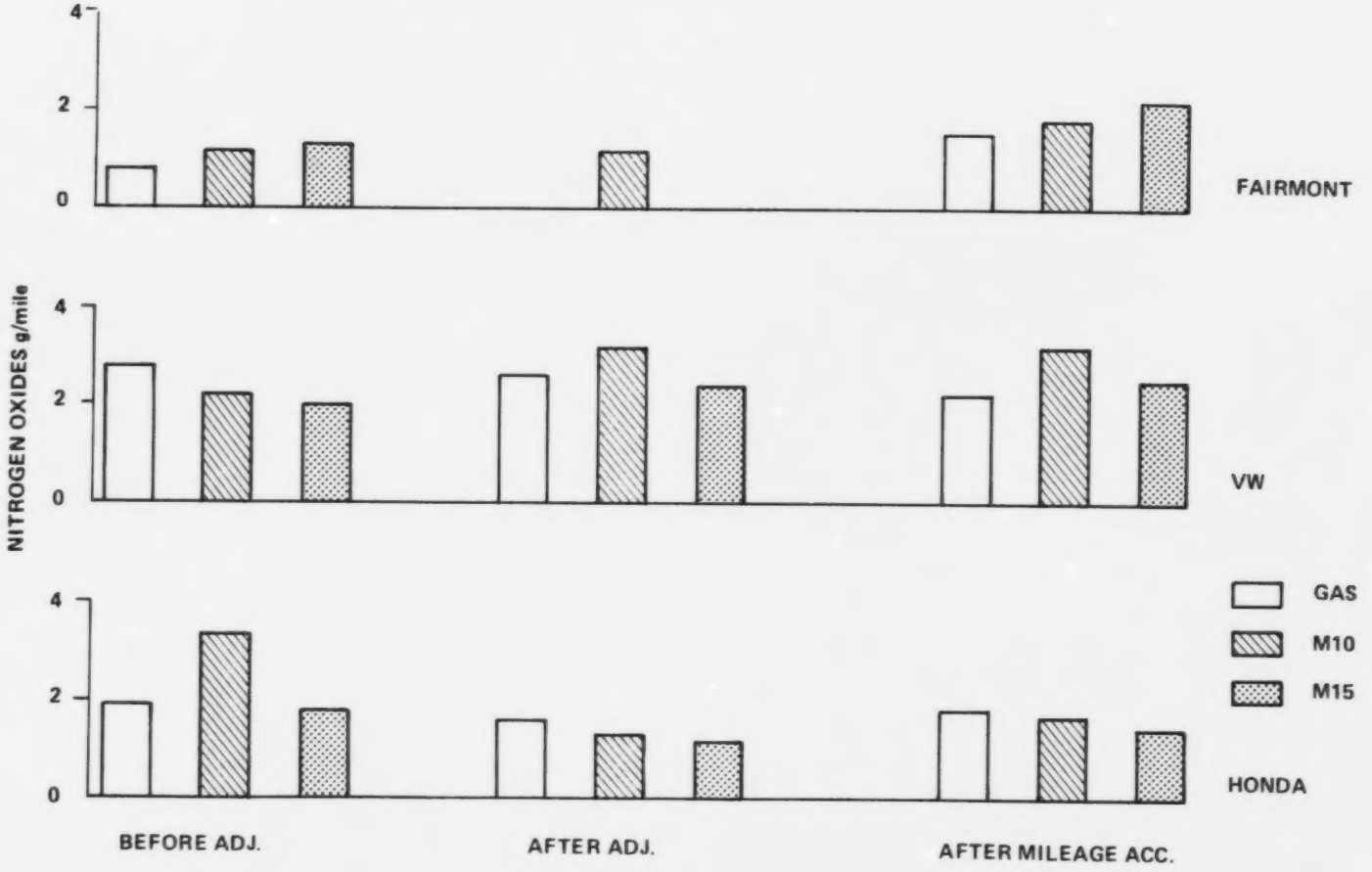

Figure 5/ Honda/VW/Ford: Emissions of Nitrogen Oxides; Gasoline, M10, M15

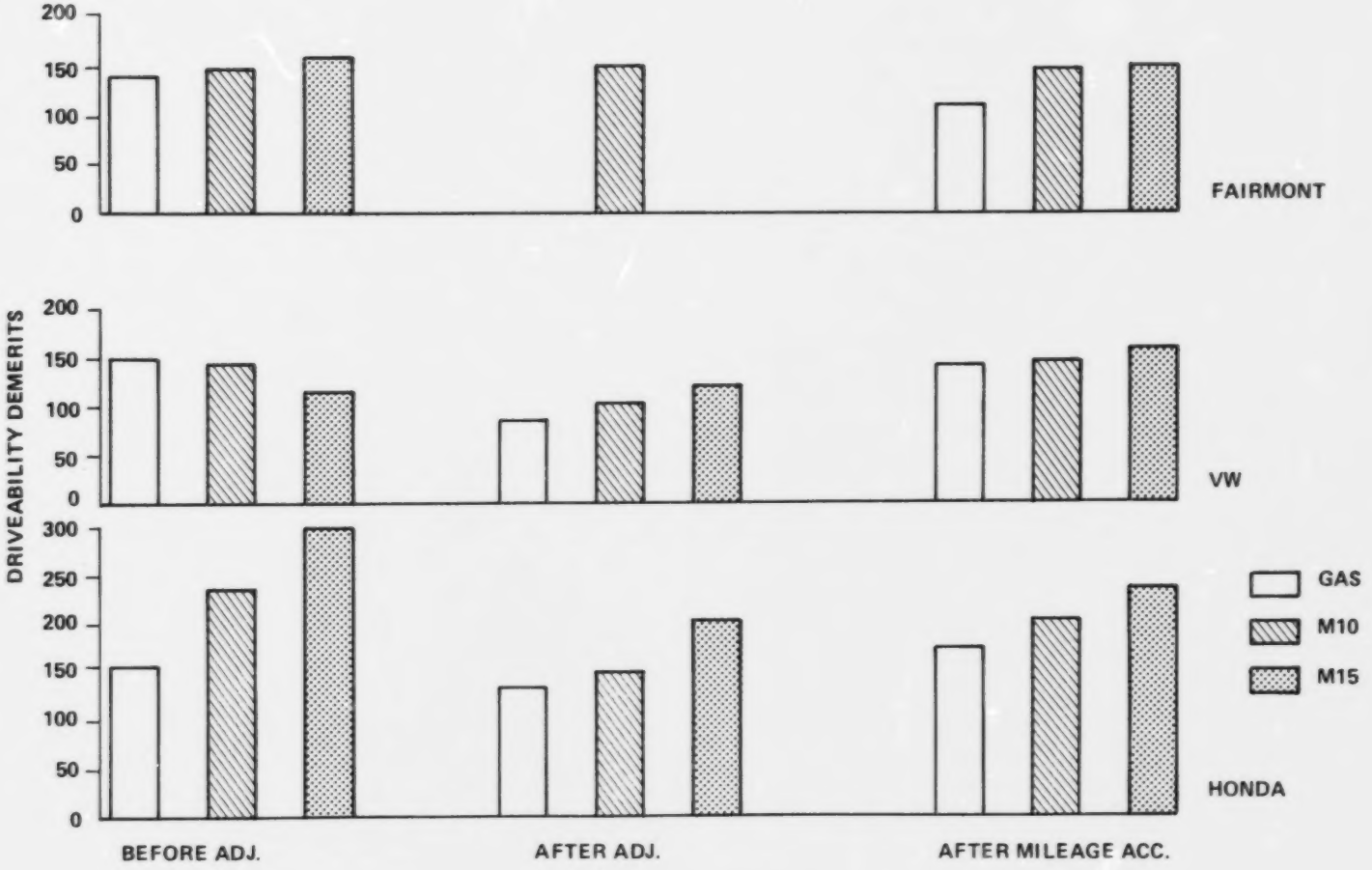

Figure 6/ Honda/VW/Ford: Cold-Start Driveability; Gasoline M10, M15

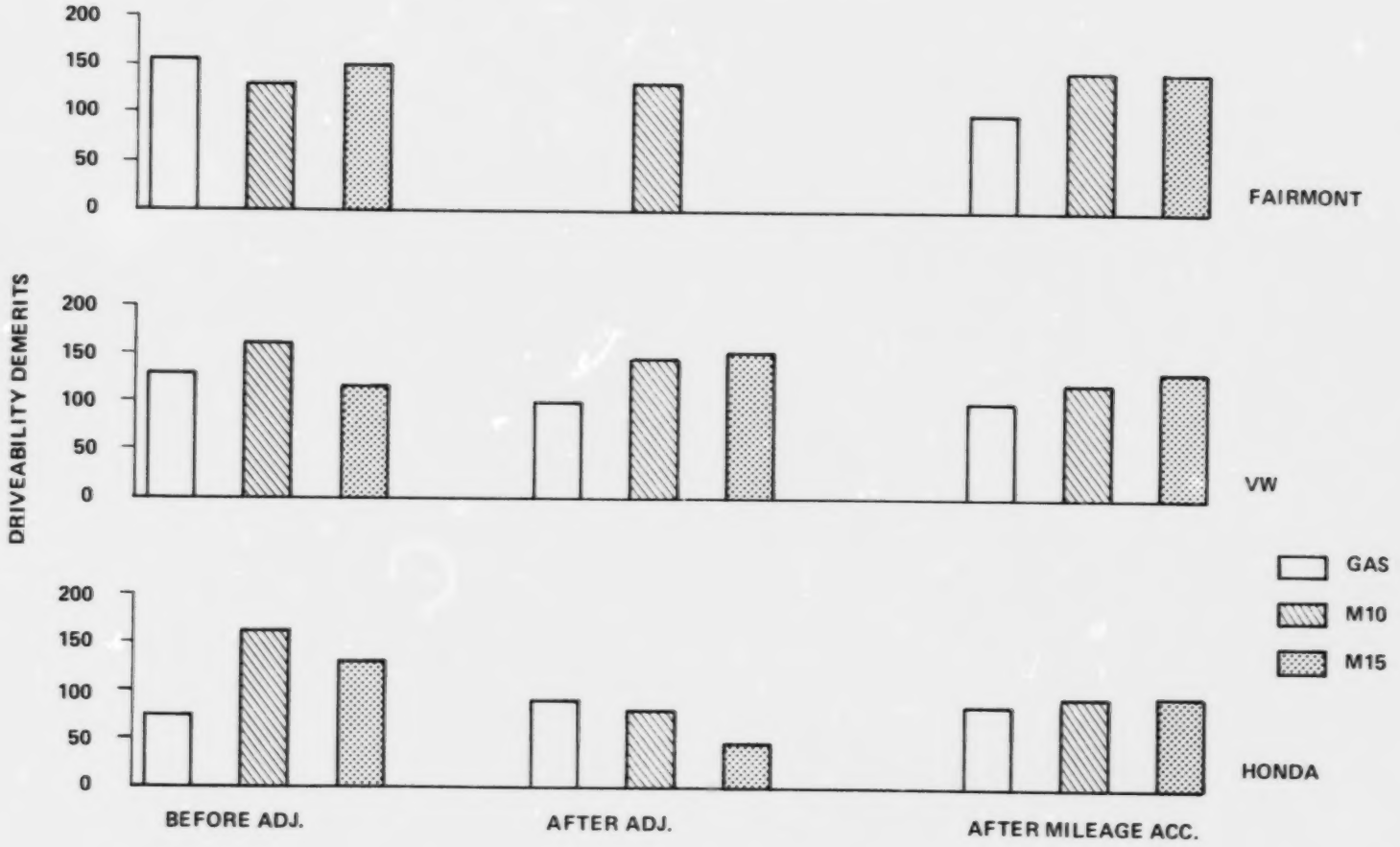

Figure 7/ Honda/VW/Ford: Hot-Start Driveabilitv; Gasoline M10, M15

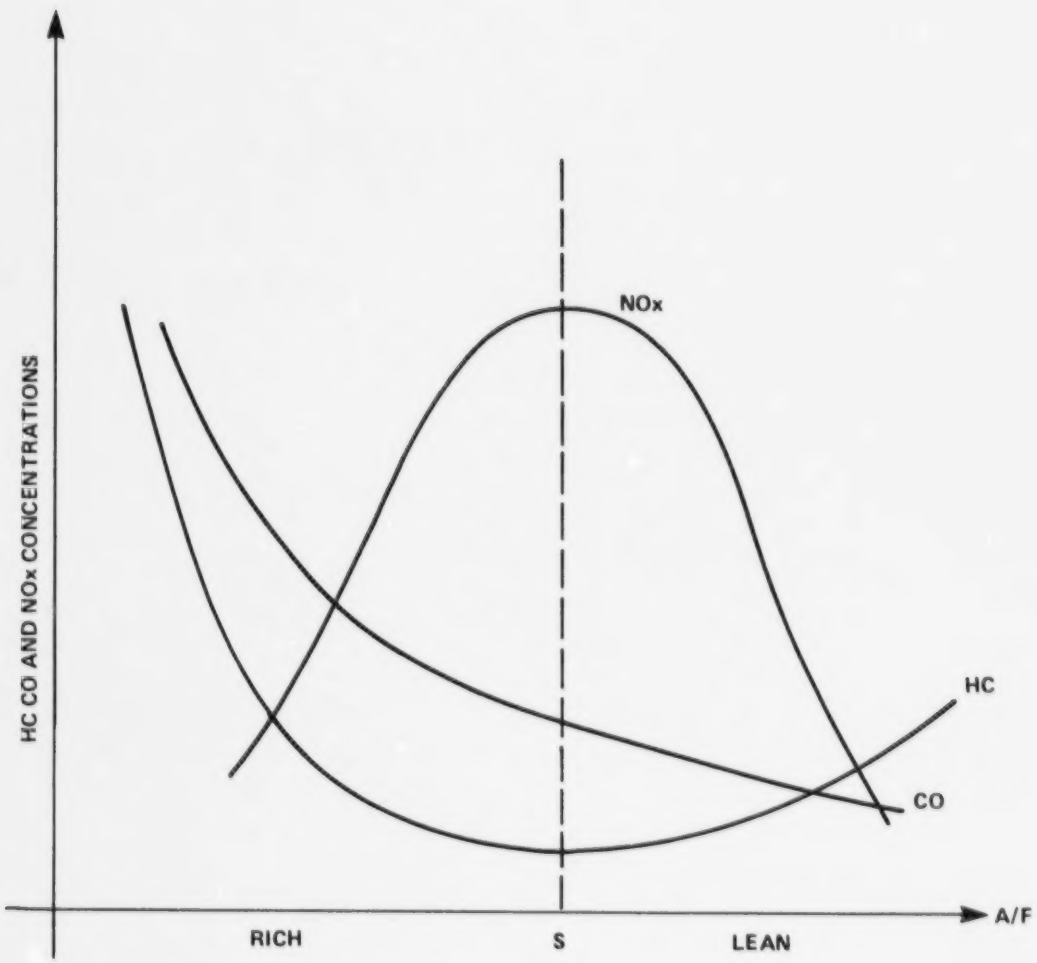

Figure 8/ Variation of Exhaust Pollutant Concentrations with Air/Fuel Ratio

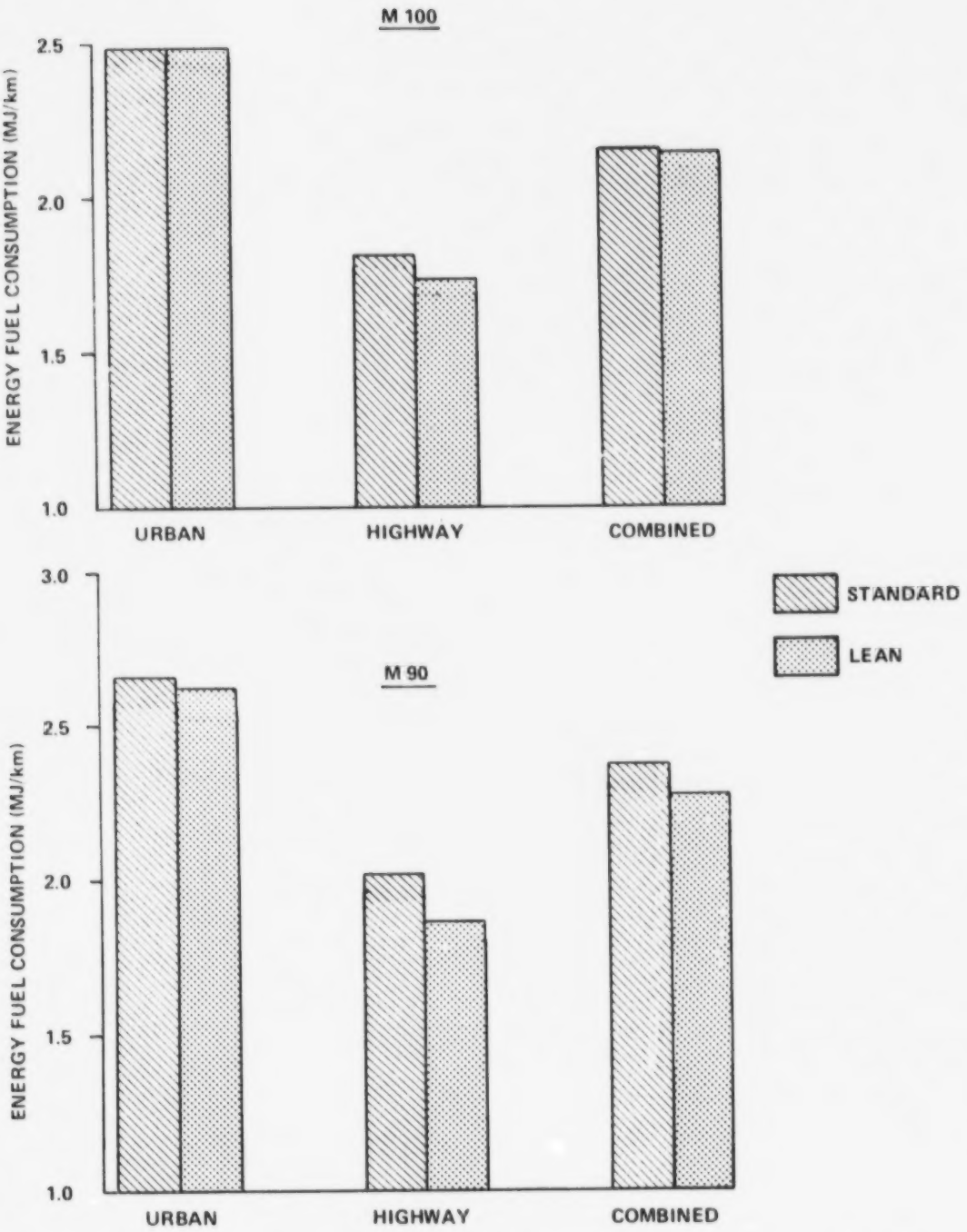

Figure 9/ VW/Golf: Energy Consumption; M90, M100

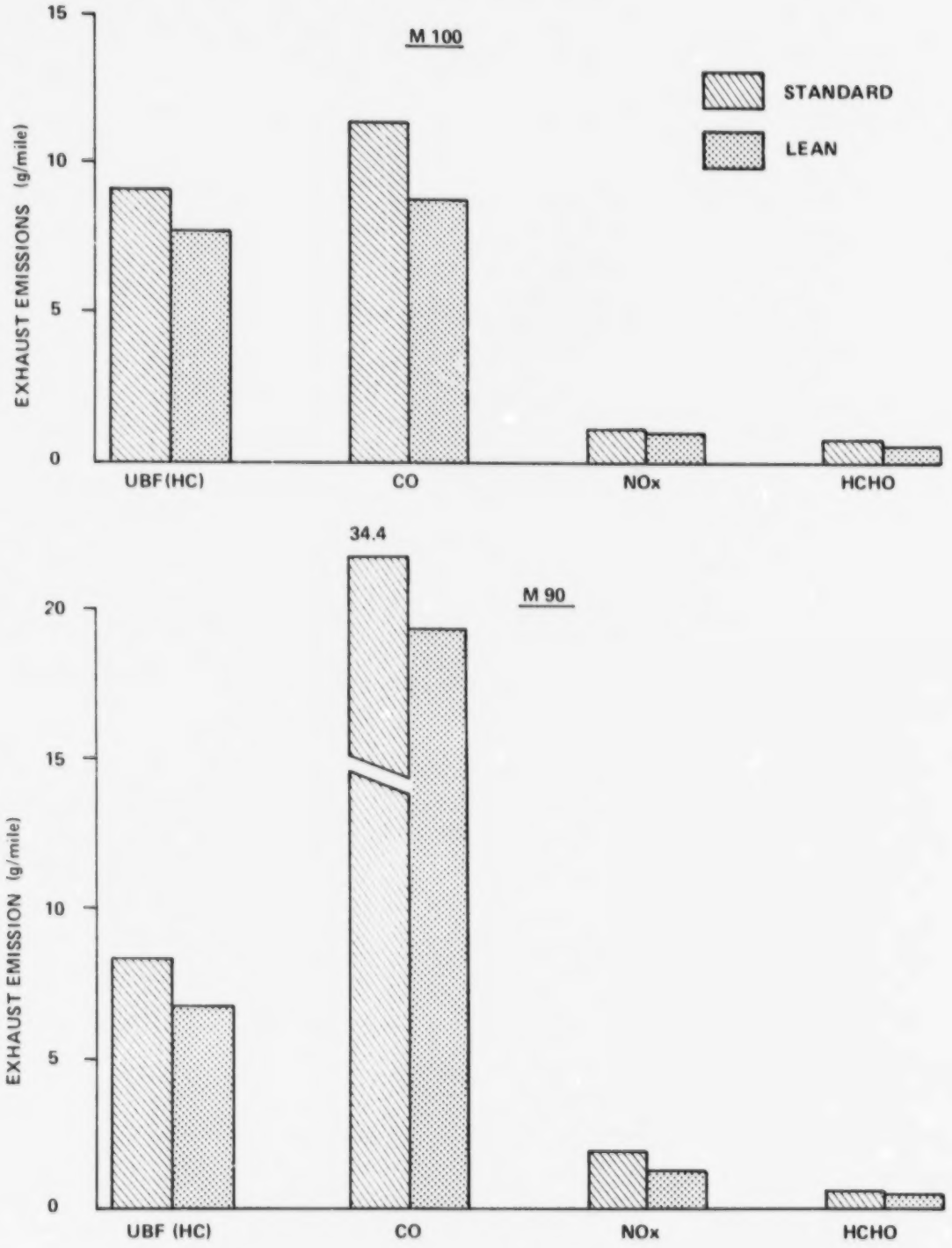

Figure 10/ VW Golf: Exhaust Emissions; M90, M100

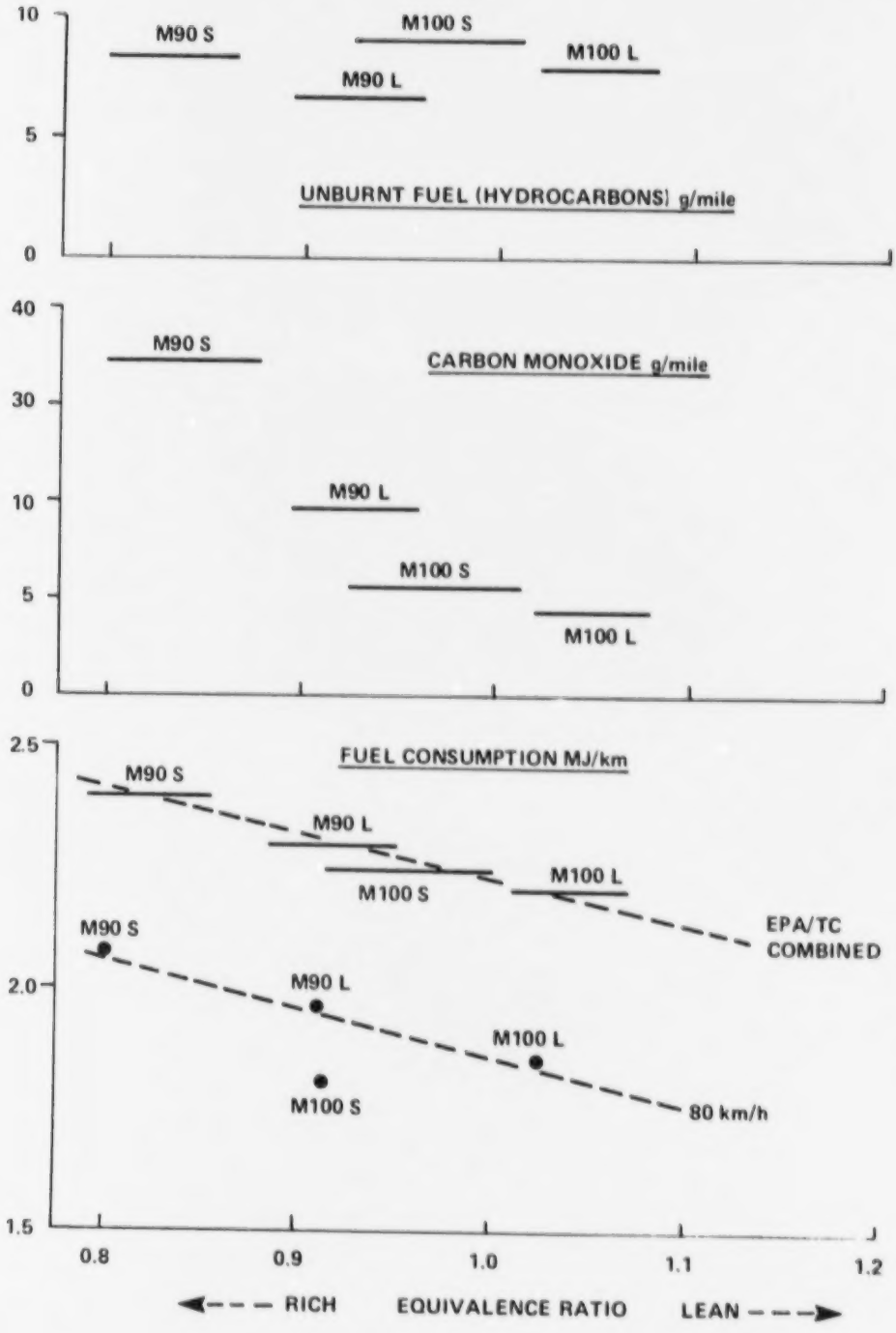

Figure 11/ VW Golf: Variation of Emissions and Fuel Consumption with Equivalence Ratio; M90, M100

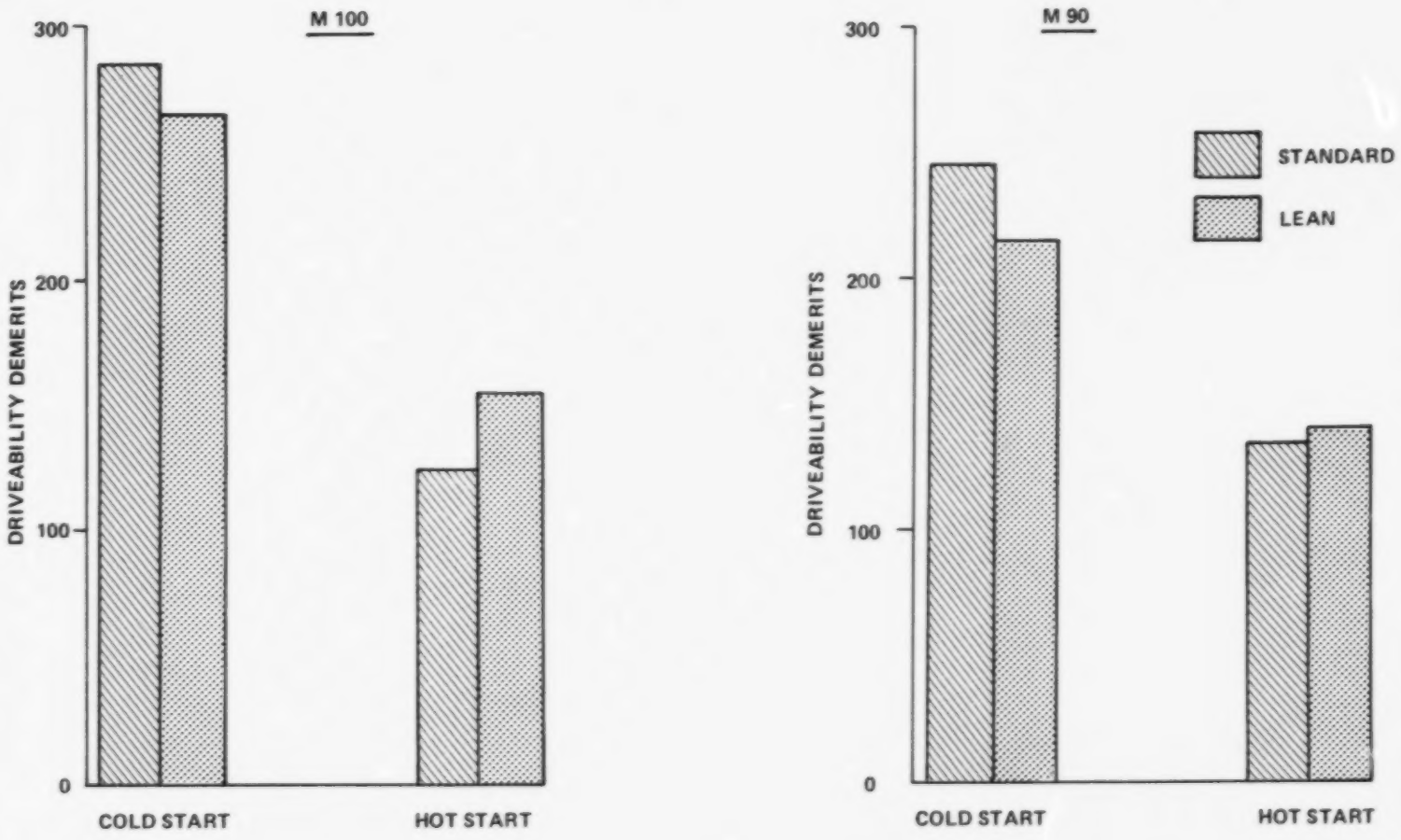

Figure 12/ VW Golf: Driveability Demerits; M90, M100

APPENDIX A/

ALDEHYDE ANALYSIS

A/ ALDEHYDES ANALYSIS

Aliphatic aldehydes react with the reagent 3-methyl-2-benzo-thiazolone hydrozone hydrochloride (MBTH) in the presence of ferric chloride to form a blue cationic dye in acidic media. The relative colour intensity can be measured in a spectrophotometer and the concentration of total aldehydes can be determined.

A.1/ Reagent and Apparatus

A 0.5% aqueous solution of MBTH was used as the collecting solution; it was filtered when necessary and was stable for at least one week.

The oxidizing agent was an aqueous solution containing 1.6% sulfamic acid and 1.0% ferric chloride.

The stock formaldehyde solution was 37.5% ACS reagent. A Bausch & Lomb Spectronic 20 was used for all quantitative colorimetric determinations.

A.2/ Preparation of Standard Curve for Exhaust Gas Analysis

To standardize the reagent, eight test solutions (ranging from 0 to 0.5 µg of formaldehyde per cc of 0.05% MBTH) was prepared. After standing one hour, 10 cc of each test solution was placed in a test tube and 2 cc of oxidizing agent added. After mixing, the tube contents were allowed to stand for at least 12 minutes for complete colour development. The absorbance was then determined on the spectrophotometer at 628 nm against a blank. Absorbance versus micrograms of formaldehyde per 10 cc of each test solution was plotted to obtain the Beer's law curve, Figure A.1.

A.3/ Procedure for Analysis of Exhaust Sample

Vehicle exhaust gas was drawn through a gas bubbler containing 350 cc of 0.05% aqueous MBTH solution. When sampling was completed, the volume was adjusted to the original 350 cc with distilled water and the solution was allowed to stand for one hour. This ensured complete reaction of the aliphatic aldehydes with MBTH. Ten cc of test solution was pipetted into a test tube, 2 cc of oxidizing agent was added, and the tube contents

were mixed thoroughly. After standing 12 minutes, the absorbance was measured at 628 nm against a blank in the laboratory. The amount of aldehydes (reported as formaldehyde) in the 10 cc test solution was readily ascertained from the absorbance concentration curve.

A.4/ Sample Calculation

Bag 1	
Sample	**Background (Air)**
Distance = 3.49 mi Total Diluted Exhaust = 81588.9 L (V mix)	
Absorbance = 1.48 Flow Rate = 113.2 L/h for 58.8 s Volume of MBTH used = 350 cc	Absorbance = 0.12 Flow Rate = 147.16 L/h for 45 s Volume of MBTH used = 150 cc

Total Amount of HCHO in Background Air (g/L) = Absorbance x Absorptivity/Vol. of B'ground Air

$$= 0.12 \times 2.13 \times 10^{-6} \times \frac{150}{10} / 147.16 \times \frac{45}{3600}$$

$$= 2.08 \times 10^{-6} \text{ g/L}$$

Amount of HCHO Collected from Sample $= 1.48 \times 2.13 \times 10^{-6} \times \frac{350}{10} / 113.2 \times \frac{58.8}{3600}$

$$= 5.967 \times 10^{-5} \text{ g/L}$$

Actual amount of HCHO in Exhaust = (HCHO in Sample - HCHO in B'ground) x $(1 - \frac{1}{DF})$

$$= 5.967 \times 10^{-5} - 2.08 \times 10^{-6} \left(1 - \frac{1}{48.8}\right)$$

$$= 5.763 \times 10^{-5} \text{ g/L}$$

Total HCHO in Exhaust = Actual HCHO x Vol. in Mix x 1.25

$$= 5.763 \times 10^{-5} \text{ g/L} \times 81588.9 \text{ L} \times 1.25$$

$$= 5.878 \text{ g}$$

Amount of HCHO per Test Phase (g/mile) = 5.878 g/ 3.49 mile

= 1.68 g/ mile

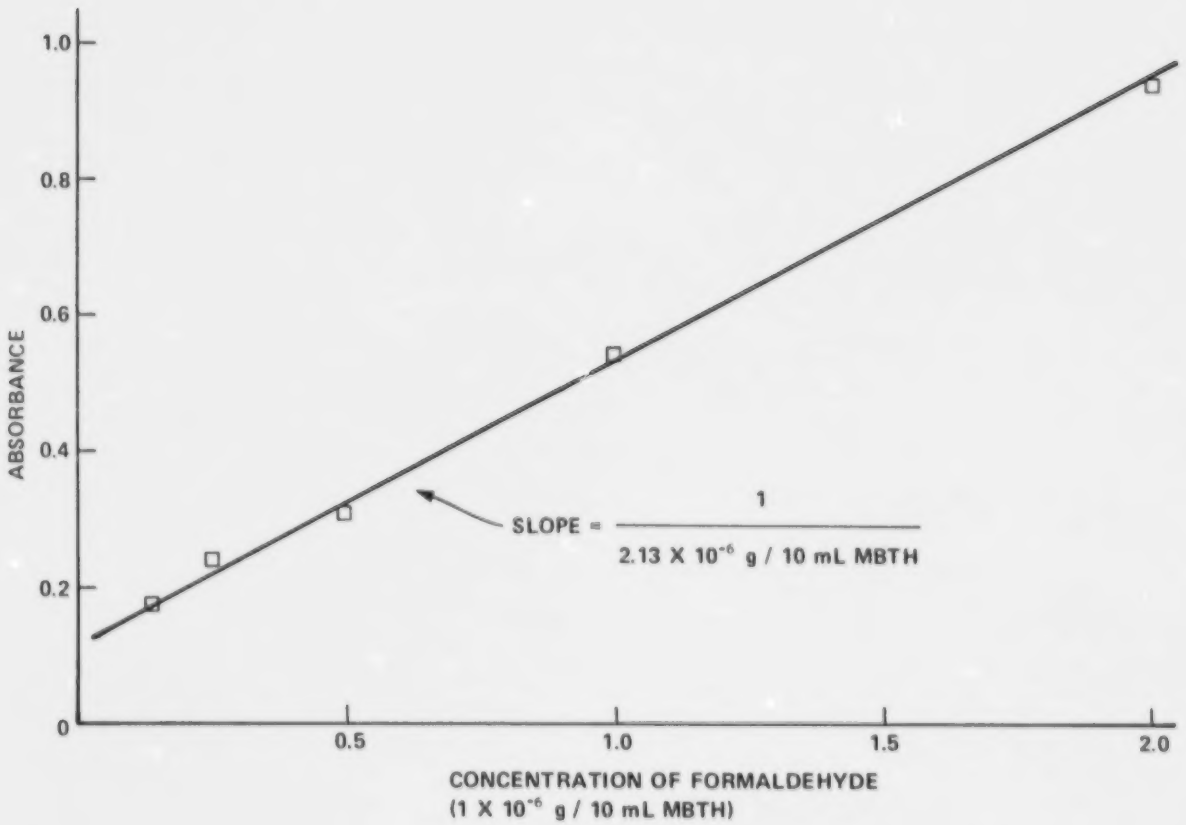

Figure A.1/ Calibration Curve for Aldehyde Analysis

APPENDIX B/

DRIVEABILITY ASSESSMENT

B/ DRIVEABILITY RATING SYSTEM

The driveability method is derived from many Co-ordinating Research Council (CRC) reports, particularly No. 489, [13]. The demerit totals are not intended to match the formal Total Weighted Demerits (TWD) index established by the CRC under their standard test conditions. In this report only comparative driveability evaluations are made.

B.1/ Objective Ratings

The magnetic tape recorder recorded the vehicle's throttle position, manifold pressure, engine rpm, road speed and engine vibration which were then reproduced on a strip-chart recording in the laboratory. The severity of each malfunction (such as hesitation, stumble, surge, or backfire) was rated as trace (T), moderate (M), or heavy (H) during each manoeuvre. A representative portion of a chart recording indicating various malfunctions is shown in Figure B.1. The demerits scale in Table B.1 was then applied to the individual chart measurement for each manoeuvre, and the demerits were summed to yield the total weighted demerits.

TABLE B.1/ DEMERITS ASSIGNED FOR EACH MALFUNCTION

LEVEL OF SEVERITY						
MALFUNCTION	TRACE(T)		MODERATE(M)		HEAVY(H)	
	DEMERITS	SCALE	DEMERITS	SCALE	DEMERITS	SCALE
Idle Roughness	1	12 mm Hg	2	20 mm Hg	4	38 mm Hg
Hesitation	6	0.25 s	12	0.5 s	24	1.1
Stumble	6	0.5 s	12	0.5 s	24	1.1
Surge	4	3.5 mm Hg	8	7 mm Hg	16	15 mm Hg
Backfire	6		12		24	
Stall (Driving)	32		32		32	
Stall (Idle)	8		8		8	
Starting Time (s - 2.0)	1		1		1	

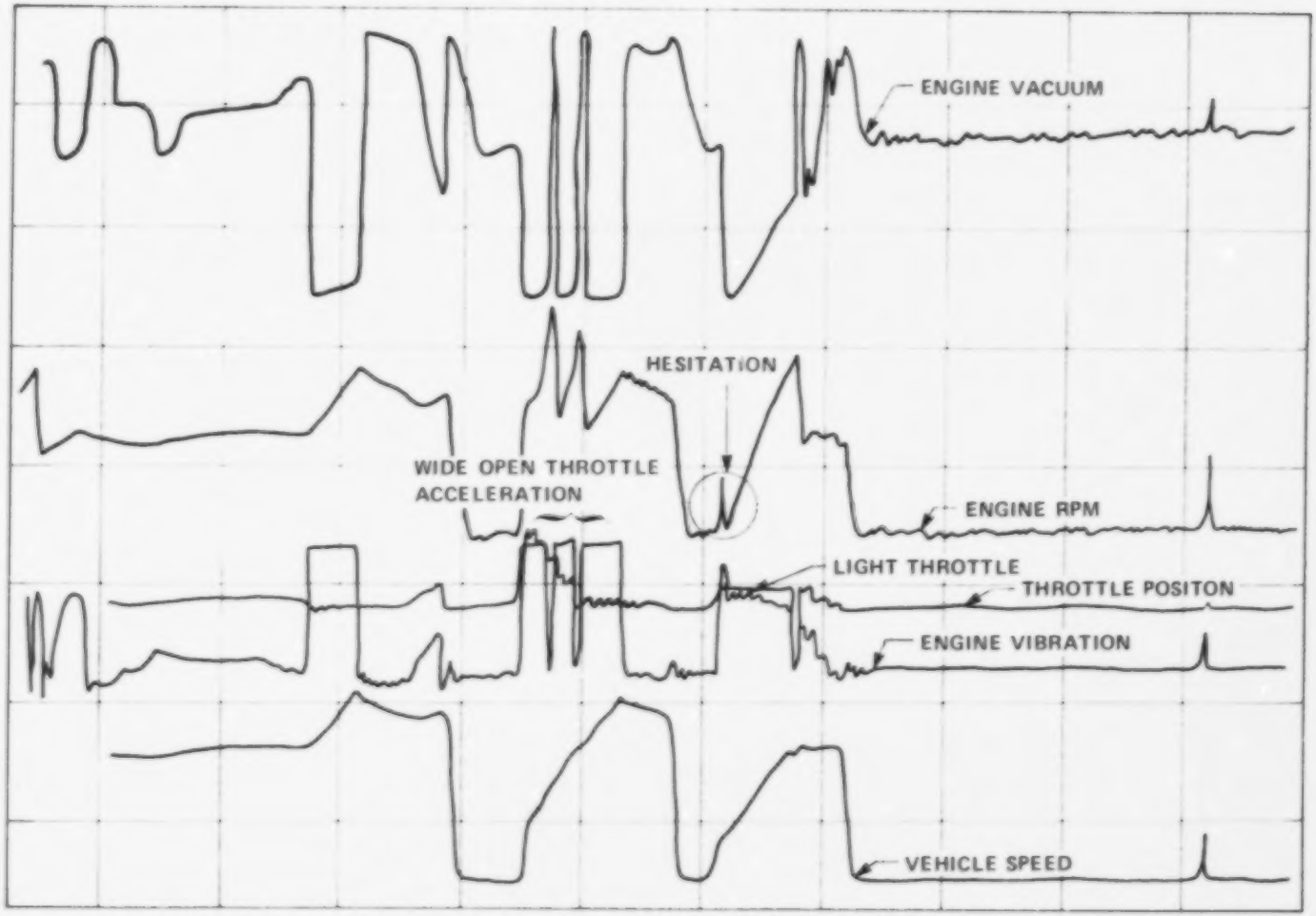

Figure B.1/ Representative Instrumentation Chart Showing Driveability Malfunction

APPENDIX C/

STATEMENT OF WORK

Contract Agreement Between MTC and Transport Canada, 1979

C/ STATEMENT OF WORK -- Contract Agreement Between MTC (Ontario) and Transport Canada (Canada), 1979

C.1/ Procedure

Up to six vehicles are to be selected as representative of advanced combustion technology and likely to be typical of the future automobile fleet.

They will first be tested on the dynamometer for fuel economy and emissions. This will be followed by driveability tests performed on the dynamometer in which instrumentation will be used to record vehicle performance as an adjunct to subjective assessments by drivers. The tests will be arranged such that the winter driving performance can be evaluated for each vehicle on gasoline, gasoline/methanol blends, or on straight methanol and ethanol as appropriate.

The following vehicle technologies and fuels will be assessed by Ontario from laboratory and practical road trials.

C.2/ Vehicles

Ontario shall purchase or rent up to four vehicles typical of the following technology for road and laboratory testing as in Sections C.4.1; 4.2; 4.3; 4.4; 4.5. The choice and number of vehicles shall be agreed with Canada.

A further two vehicles will be supplied from Ontario's fleet. Vehicles within the listed technology categories are given as examples.

Engine Technology	Examples of Vehicles (Existing or Projected, 1979)
Stratified Charge	Honda CVCC; White TCCS
Fuel Injection	VW Rabbit; Volvo, SAAB Cadillac Seville
Three-Way Catalyst with Closed Loop Control	Ford Fairmont; Buick; Volvo; SAAB
Straight Methanol Engines	Ford Escort, VW

Note 1: All vehicles shall be fully insured by Ontario.

C.3/ Test Fuels

Test fuels to be supplied and mixed by Ontario. The composition of the test fuels used will be those agreed with Canada.

C.3.1/ Methanol

The methanol used shall be a fuel grade formulated to contain 10% higher alcohols and for straight methanol use, a hydrocarbon additive, such as iso-pentane will be used to raise volatility. Proportions are to be specified and agreed to by the Scientific Authority.

C.3.2/ Ethanol

For straight ethanol use, the ethanol shall be industrial grade containing 5% methanol. Hydrocarbon additives such as iso-pentane will be used to raise volatility as specified and agreed to by the Scientific Authority.

C.3.3/ Gasoline

The base (reference) gasoline shall be specified and agreed to by Canada. The composition of the gasoline shall be specified by its percentage of aromatic content.

C.3.4/ Methanol/Gasoline Mixtures, Straight Methanol and Ethanol Fuels

Fuel mixtures will be made by MTC for test purposes under specifications agreed to by the Scientific Authority. Records of the fuel composition and its use will be kept together with any periodic determination of water content. Complete records of the cost and quantities of fuels shall be kept for contract purposes and periodically summarized for invoicing.

C.4/ Test Program (To be carried out by Ontario)

Vehicle adjustment will be made at the commencement of the dynamometer and driveability tests to ensure compliance with the manufacturer's recommendations.

The testing periods allocated for the tests described below, in C.4.1 to C.4.5, include allowance for down time and waiting time for the use of the facilities.

C.4.1/ Vehicle Adjustment, Fitting for Test and Road Load Determination: Approximately Four Weeks/Vehicle

Ontario shall adjust each vehicle at the commencement of tests (and subsequently as deemed necessary) such that it complies with the manufacturer's specification. In particular the timing, idle adjustment, spark plug gaps and distributor contact gap shall be inspected and set. Records of adjustments on each vehicle will be kept.

The vehicles will be fitted with transducers, and auxiliary fuel tanks. Also, Ontario will make any other equipment changes it considers necessary for operating on fuel blends, and full records of such changes shall be made.

On the completion of the above adjustment and fitting, short driving periods will be made to check vehicle performance before proceeding with the test in Item C.4.2.

Road load determination will be made as specified in the Transport Canada "Fuel Consumption Test Methods".

C.4.2/ Dynamometer Tests (by Ontario): Three Weeks for Each Test Fuel

C.4.2.1/ Constant Speed Tests

Each vehicle shall be run at a range of constant speeds at the previously determined road load setting. Measurements of fuel consumption and air/fuel ratio shall be made.

C.4.2.2/ Standard Fuel Economy and Emission Tests

Each vehicle shall be subjected to standard fuel economy and emission tests under the urban and highway driving cycle as in the standardized Transport Canada "Fuel Consumption Test Methods." Full records of each test shall be made for each vehicle. Measurements may be made of non-hydrocarbon emissions such as alcohols and aldehydes under test conditions to be agreed on by the Steering Committee.

Note:-- For each vehicle, a dossier shall be kept containing the tests that were made and their results, inclusive of a summary report on the findings.

C.4.2.3/ Driveability Tests

Each vehicle will be subjected to dynamometer tests in which records and measurements will be made to assess the vehicle's driving performance under the following conditions:

- cold start and warm up,
- hot start and warmed up operation, and
- acceleration tests.

The tests will be made with on-board instrumentation to record various engine performance parameters for a predetermined and agreed period. In particular, vehicle hesitation, surge, stumble and power loss will be recorded to be evaluated later on an agreed demerit scale. At the same time, subjective observations will be recorded by the driver/operator. Together, these will be used to characterize the driveability performance of the vehicle according to a schedule based on the U.S. Co-ordinating Research Council (CRC).

C.4.3/ Engine Readjustment (by Ontario)

If driveability is considered unacceptable, engine adjustments may be needed to restore acceptable performance. These could include changes in idle speed, choke setting and timing, depending on the particular engine. Following these adjustments, dynamometer tests will be repeated as detailed in Section C.4.2 and may include the following additions.

C.4.3.1/ Special Drive Cycle Tests for Fuel Economy and Emissions

These may comprise:

- a particular cycle or cycles proposed by Ontario
- subject to prevailing ambient conditions, low temperature tests of standard drive cycles as in C.4.2.2 above, or special drive cycles as mutually agreed on by Ontario and Canada.

C.4.3.2/ Road Tests for Driveability

Instrumented and subjective tests are to be carried out on the road according to the schedule described in C.4.2.3.

C.4.4/ Road Tests (by Ontario): 12 to 20 Weeks/Vehicle

Ontario shall pass the vehicle into fleet service after having completed the program described in C.4.1 - 4.3. The periods for fleet service will be arranged so that each vehicle on methanol/gasoline fuel blends or straight alcohol, as appropriate for a period in each season, will have performance data representative of operation in all Canadian climatic conditions. The fleet service will accumulate an average of about 100 miles per day per seasonal period. A daily report sheet will be filled out by the operator to record such things as date, time, temperature, time to start from cold, trip length and identification, and the start and finish time of each trip.

Ontario shall make periodic checks for fuel separation and component deterioration during the period of service. Normal garage service checks will also be carried out based on mileage (approximately every 3000 miles).

C.4.5/ Repeat Tests Following Road Tests

To determine the effect of the road-test experience, on its completion Ontario will pass the vehicle through a further set of tests. The tests will be comprised of the dynamometer fuel economy, and the emissions and driveability tests (C.4.2), but will exclude constant speed tests. The results of these tests will be compared with the prior tests and an interim summary of the vehicle assessment shall be made.

C.5/ Testing Sequence (To be carried out by Ontario)

C.5.1/ Arrangement of Testing

To accommodate full evaluation of six vehicles, Ontario will probably operate a two-phase testing system. This will maintain maximum utilization of the test facilities, and the technical and engineering staff and so will ensure continuity of testing and evaluation procedures.

It is envisioned that at any one time, two vehicles will be set-up and undergoing laboratory tests (Phase A or Phase C) while the others are

undergoing road tests (Phase B), thus alternating the laboratory occupancy for the three vehicles. The test sequence and the times allotted should be regarded as provisional. Delay may be expected during initial start up, holiday periods and other unspecified interruptions.

C.5.2/ Definition of Testing Phases

Phase A

This shall consist of:

Period of four weeks	- setting up vehicle and road load determination (Item C.4.1);
Period of three weeks (for each fuel mixture)	- dynamometer, fuel economy, emission and driveability (Item C.4.2);
Period of three weeks (for each fuel mixture)	- engine adjustments if necessary and further tests (Item C.4.3).

Phase B

Variable: 8 - 20 weeks - vehicle on road service (Item C.4.4).

Phase C

This shall consist of one week plus the following:

Period of two weeks (for each fuel mixture)	- Dynamometer tests as in Item C.4.2 but excluding constant speed tests.

C.5.3/ Selection of Fuels

The selection of fuels for particular vehicles and the appropriate test sequence shall be conducted as specified and agreed on with Canada. Standard gasoline engines (such as the Honda CVCC and VW Rabbit) shall be tested with gasoline, 10% and 15% methanol mixtures, and test sequences shall include the adjustment tests in Item C.4.3.

Self-adjusting vehicles (three-way catalyst) shall be tested with gasoline, 10% and 15% methanol-gasoline mixtures and adjustment tests (Item C.4.3) will be omitted.

The broad-cut fuel engine (White TCC5) shall be tested with gasoline, straight methanol fuel, straight ethanol fuel and high methanol gasoline blends, e.g., 80% methanol, with optimized adjustments for each one as supplied by the manufacturer.

Methanol fuel engines will be tested with two specifications of straight methanol fuel.

C.5.4/ Estimated Plan Project Duration

Allowing a period for final and executive report preparation, the duration of the project is estimated to be 130 weeks (amended 82-03-15 to 165 weeks).

APPENDIX D/

FUEL ANALYSES

Table D.1/ GASOLINE ANALYSIS BY MASS SPECTROMETRY AND GAS CHROMATOGRAPHY
(Sample No. MTC-01)

Z No	HYDROCARBON TYPE	VOLUME PERCENT		CARBON No. %										
				3	4	5	6	7	8	9	10	11	12	13
+2	Paraffins	72.1		0.1	12.7	14.1	- remainder -							
0	Monocycloparaffins	4.5												
-2	Dicycloparaffins	0.3	5.2											
-4	Tricycloparaffins	0.4												
0	Mono-olefins	5.8		0.0	0.4	2.7	1.1	0.6	0.5	0.3	0.1	0.1	0.0	0.0
-2	Cyclo-olefins	1.0	7.0											
-4	Dicyclo-olefins	0.2												
-6	Alkylbenzenes	15.3					0.7	3.8	6.5	3.6	7.0	0.0	0.0	0.0
-8	Indanes	0.3												
-10	Indenes	0.1	15.7											
-12	Naphthalenes	0.0												
-14	Biphenyls	0.0												
		100.0												

VOLATILITY CHARACTERISTICS OF GASOLINE (Sample No. MTC-01)

Reid Vapour Pressure (kPa):	86
Boiling Point Range (°C):	
Initial Boiling Point	32
10%	38
20%	49
50%	98
90%	158
Final Boiling Point	201
Recovery	95%
Residue	0.75%
Loss	4.2%

Table D.2/ GASOLINE ANALYSIS BY MASS SPECTROMETRY AND GAS CHROMATOGRAPHY (Sample No. MTC-02)

Z No.	HYDROCARBON TYPE	VOLUME PERCENT		CARBON No. %								
				4	5	6	7	8	9	10	11	12
+2	Paraffins	60.0		5.0	10.5	- remainder -						
0	Monocycloparaffins	6.4										
-2	Dicycloparaffins	0.3	6.7									
-4	Tricycloparaffins	-										
0	Mono-olefins	11.0		1.0	4.2	3.3	1.4	0.6	0.2	0.2	0.1	
-2	Cyclo-olefins	2.1	13.2									
-4	Dicyclo-olefins	0.1										
-6	Alkylbenzenes	19.8				1.0	4.0	6.4	6.4	1.9	0.1	
-8	Indanes	0.3										
-10	Indenes	-	20.1									
-12	Naphthalenes	-										
-14	Biphenyls	-										
		100.0										

VOLATILITY CHARACTERISTICS OF GASOLINE (Sample No. MTC-02)

Reid Vapour Pressure (kPa):	63
Boiling Point Range (°C):	
Initial Boiling Point	30
10%	49
20%	62
50%	100
90%	168
Final Boiling Point	208
Recovery	98.5%
Residue	1.0%
Loss	0.5%

Table D.3/ GASOLINE ANALYSIS BY MASS SPECTROMETRY AND GAS CHROMATOGRAPHY
(Sample No. MTC-03)

Z No.	HYDROCARBON TYPE	VOLUME PERCENT		CARBON No. %								
				3	4	5	6	7	8	9	10	11
+2	Paraffins	47.7		0.1	8.2	9.7	29.7 -					
0	Monocycloparaffins	6.0										
-2	Dicycloparaffins	-	6.0									
-4	Tricycloparaffins	-										
0	Mono-olefins	10.6			1.1	5.0	2.9	0.9	0.3	0.2	0.1	0.1
-2	Cyclo-olefins	1.4	12.0									
-4	Dicyclo-olefins	-										
-6	Alkylbenzenes	33.9					1.8	7.0	12.3	10.7	2.1	
-8	Indanes	0.4										
-10	Indenes	-	34.3									
-12	Naphthalenes	-										
-14	Biphenyls	-										
		100.0										

VOLATILITY CHARACTERISTICS OF GASOLINE (Sample No. MTC-03)

Reid Vapour Pressure (kPa):	61
Boiling Point Range (°C):	
Initial Boiling Point	31
10%	44
20%	58
50%	108
70%	141
90%	162
Final Boiling Point	204

APPENDIX E/

FUEL HEATING VALUES

E/ CALCULATION OF FUEL HEATING VALUE

E.1/ Gasoline

For a hydrocarbon mixture characterized by a H/C ratio of n, the combustion may be represented as follows:

$$'CH'_n + (1 + n/4)O_2 \rightarrow CO_2 + n/2\ H_2O$$

$$(12 + n)\ kg \qquad (n/2) \times 18\ kg$$

$\therefore$ 1 kg of fuel liberates $\frac{9n}{12 + n}$ kg of H_2O

Now, the latent heat of water = 2.46 MJ/kg
(25C°)

$\therefore$ LHV is less by $\frac{9n}{12 + n} \times 2.46$ MJ/kg

= 2.89 MJ/kg n = 1.8
= 3.16 MJ/kg n = 2.0

For a gasoline of 30% aromatics
70% saturates

UHV = 46.3 MJ/kg

$\therefore$ LHV = 43.4 MJ/kg n = 1.8
= 43.2 MJ/kg n = 2.0

The hydrogen to carbon ratio is assumed to be 1.8 for all the gasoline used in this program and the lower heating value is 43.4 MJ/kg.

Table E.1/ COMPOSITION AND ENERGY CONTENT OF METHYL FUEL M100 (assuming ideal mixing)

Component/ Molecular Weight	Density	Volume in 1 L Mix	MASS				Moles /L	Mass Water Formed g(mole)	UHV (MJ)
			Total	Carbon %	Hydrogen %	Oxygen %			
				kg/L	kg/L	kg/L			
Methanol 32.042	0.792	0.9	0.7128	37.48%	12.58%	49.93%	22.25	0.8016	16.27
				0.2672	0.0897	0.3559			
Ethanol 46.068	0.789	0.02	0.0158	52.14%	13.13%	34.73%	0.34	0.0185	0.47
				0.0082	0.0021	0.0055			
n-Propanol 60.094	0.804	0.03	0.0241	59.96%	13.42%	26.62%	0.40	0.0289	0.811
				0.0144	0.0032	0.0064			
isobutanol 74.12	0.802	0.05	0.0401	64.81%	13.6%	21.59%	0.542	0.0488	1.448
				0.0260	0.0055	0.0087			
Total		1.00	0.7928	39.83%	12.68%	47.49%		0.8978	18.899
				0.3158	0.1005	0.3765			

UHV = 23.51 MJ/kg 18.90 MJ/L

LHV = 20.72 MJ/kg 16.699 MJ/L

$$\text{Formula Wt} = \frac{0.7928}{0.3158} \times 12.01 = 30.15$$

Formula = $C_1 H_{3.791} O_{0.894}$

Table E.2/ COMPOSITION AND ENERGY CONTENT OF M90 (assuming ideal mixing)

Component/ Molecular Weight	Density	Volume in 1 L Mix	MASS				Moles /L	Mole of water formed g(mole)	UHV (MJ)
			Total	Carbon %	Hydrogen %	Oxygen %			
				kg/L	kg/L	kg/L			
Methanol 32.042	0.792	0.810	0.6415	37.48%	12.58%	49.93%	20.02	40.04	14.55
				0.2404	0.0807	0.3203			
Ethanol 46.068	0.789	0.018	0.0142	52.14%	13.13%	34.73%	0.308	0.924	0.4217
				0.0074	0.0019	0.0049			
n-Propanol 60.094	0.804	0.027	0.0217	59.96%	13.42%	26.62%	0.3612	1.4448	0.7302
				0.0130	0.0029	0.0058			
isobutanol 74.12	0.802	0.045	0.0361	64.81%	13.6%	21.59%	0.4869	2.4345	1.3038
				0.0234	0.0049	0.0078			
iso-Pentane 74.12	0.6262	0.10	0.0626	83.24%	16.76%	0	0.8679	5.2074	3.0481
				0.0521	0.0105				
Total		1.00	0.7761	43.33%	13.00%	43.65%		50.0507	20.05
				0.3363	0.1009	0.3388			

UHV = 20.05 MJ/L

LHV = 18.00 MJ/L

FORMULA = $C_1 H_{3.575} O_{0.756}$

APPENDIX F
VEHICLE SERVICE RECORD

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* NOTE: -- The Ford Fairmont Vehicle encountered no observed service problems and is not included in this service record. Service actions carried out for the WHITE/TEXACO Gremlin were concerned solely with the adjustment of the fuel pump and are detailed in in Section 6.2 of the main report.

F.1/ VW RABBIT

F.1.1/ Introduction

Methanol blends were first used in this vehicle, which was acquired new, for several types of road tests in March and April of 1978. Subsequent to these tests, the vehicle was used in general service, with an occasional tank of M10 or M15 fuel.

Early in 1980, this vehicle started blend tests for the Federal-Provincial Methanol Vehicle Test Program consisting of dynamometer tests of the EPA type, constant speed to duplicate road load, driveability tests, and some acceleration tests using no-lead gasoline, M10 and M15 fuels.

Then after a period of mileage accumulation on M10, the dynamometer tests were repeated on no-lead gasoline, M10 and M15 fuel to quantify the extent of degradation due to the use of the methanol blends.

F.1.2/ CHRONOLOGICAL LIST OF SERVICE ACTIONS: VW Rabbit

DATE	ODOMETER (miles)	DESCRIPTION OF EVENT
77-4-17 To 78-3-18	0 To 2534	General break in mileage and installation of test equipment for road load fuel consumption - gasoline
78-3-18	2534	M15 - Road load fuel consumption.
78-3-20	3102	M20 - Road load fuel consumption.
78-3-31	3454	M25 " " " "
78-4-4	3641	M30 " " " "
78-5-5	3930	M40 " " " "
78-5-7	4036	M50 " " " "
78-5-13	4391	M40 " " " "
78-5-17	4581	M10 " " " "
78-5-24	4870	M20 " " " "
78-5-25	4980	Gasoline - Road load fuel consumption.
78-5-26 To 78-9-20	5240 To 6143	General service for MTC.
78-9-25	6156	M85 + 5% water + 10% non-leaded gasoline - two turns rich on screw adjustment on fuel distributor - local area test drive. Poor driveability but operated reasonably well at constant speeds. At the end of the day the mixture in the fuel tank was adjusted to about M10, and the fuel distributor reset to specifications.
78-10-3	6161	M10
78-10-30	6302	Gasoline
79-7-5	8298	M15 - Hard starting when cold.
79-7-16	8532	Gasoline - Hard starting cold, and when started the engine missed badly for about one minute before clearing up. Acceleration was not good, the engine seemed to be missing under load. The vehicle was returned to the MTC garage. While the mechanic was road testing the vehicle, it stalled, the engine would not start, and it was eventually towed to JUST VOLKSWAGEN for repairs. Repairs at JUST VOLKSWAGEN: - Shorted out electrical panel, a new one was installed. - changed two fuel injectors - changed cold start valve - changed fuel filter - changed fuel distributor - changed electric fuel pump

DATE	ODOMETER (miles)	DESCRIPTION OF EVENT
		Total cost - over $1100.00. On inspection, the only part that failed was the four "O" rings in the fuel distributor block which separate the fuel lines from each other, so all the fuel was going to one cylinder, flooding it and starving the others.
79-8-21	8600	The vehicle was picked up at JUST VOLKSWAGEN. On arrival at MTC the alternator was not working, nor were the windshield wipers, washers or the rear window defogger. The vehicle was returned to JUST VOLKSWAGEN and these items were repaired.
80-1-24	9648	A fuel metering system was installed for road fuel consumption. This was the start of the Federal-Provincial Alternative Fuel Program with this vehicle.
80-2-12	9766	Constant speed tests for fuel consumption at New Lowell, Ont. Idle speed was occasionally high.
80-2-13	9990	High idle rpm was caused by a lack of electrical power to the air bypass valve. The wire feeding power to this unit had been cut. A bypass wire was installed and idle speed was normal. Timing and emissions were checked to specifications.
80-2-18 To 80-3-28	10223 To 11602	Dynamometer used for EPA, constant speed fuel consumption and driveability on no-lead gasoline.
80-3-28 To 80-5-27	11602 To 12573	Dynamometer used for EPA, constant speed fuel consumption and driveability on M10 and M15 fuels; engine adjusted to manufacturer's specifications; timing at 3° ATDC.
80-5-27 To 80-6-9	12573 To 12799	The engine was optimized for M10 fuel by advancing spark timing 3° to 0°BTDC and readjusting the fuel system to minimize emissions. EPA and other dynamometer checks were repeated. NOTE: During the preceding M10 and M15 tests, hot starting was a severe problem.
80-6-16 To 80-7-21	12799 To 13387	The engine was optimized for M15 fuel by advancing timing by 6° to 3° BTDC and adjusting for minimum emissions, e.g., 0.2% CO and 75 ppm hydrocarbons. The engine idle speed was surging from 800 to 1000 rpm. EPA dynamometer and checks of all previous driving cycles were repeated.
80-7-24	13405	The engine was reset to standard timing specifications and emissions for no-lead gasoline.

DATE	ODOMETER (miles)	DESCRIPTION OF EVENT
80-8-24	13747	The front brakes were inoperative. The front brake pads and rotors were changed. The brakes were still ineffective.
80-10-24	13951	1981 front calipers, brake pads and rotors were installed. Brake efficiency improved to an acceptable standard.
80-10-23	14011	M10 durability test was started to go to 22 000 miles or more. Changed to regular gasoline.
80-12-15	15359	M10 fuel again, mixed daily.
81-12-22	15454	M10 fuel from 1000 gallon storage tank used for fill up.
81-02-20	16320	Hot start problem. The spindle on the fuel distributor was leaking M10 fuel onto the air cleaner element causing a rich mixture when trying to start the engine. The fuel distributor, which had been rebuilt with fluorosilicone seals, was installed and the engine readjusted to M10 specifications and emissions.
81-03-04	16635	Very hard starting cold - 5 min. The engine had a sudden power loss and had to be towed in. The engine was out of fuel due to an error in the fuel gauge, but the distributor points were also out of adjustment.
81-04-02	19687	Severe hot start problems. Fast idle occasionally.
81-04-09	20835	No power in any gear. The distributor points were not opening again. Installed new Motorcraft points #DPE-131, checked timing of camshaft, flywheel timing mark, and all were OK. Timing for M10 was set at 0°BTDC. Vehicle operation was improved to near standard performance.
81-04-13	21000	Severe hot start problems.
81-04-30	23459	Conclusion of durability test.
81-04-30	23459	Reinstall driveability test equipment.
81-05-01	23505	Tune up check - 0°BTDC. Idle 980 rpm Dwell 51°. Emissions specifications for M10 fuel.

DATE	ODOMETER (miles)	DESCRIPTION OF EVENT
81-05-04	23510	M10 and M15 dynamometer tests of all EPA and other driving cycles, changing timing and emissions as required.
81-06-15	24401	Readjust to gasoline standard conditions: spark 3°ATDC, idle 970 rpm dwell 49°, standard emissions, for no-lead gasoline dynamometer tests.
81-06-16	24444	The engine stopped during a dynamometer test run. Checking fuel injection system pressure revealed that the control pressure regulator was regulating too high, causing a lean mixture. Pressures were cold 54 psi, hot 58 psi. Specifications were cold 25 psi 2#, hot 50 psi 3#. A used control pressure regulator was available and installed. Cold pressure was 38 psi and hot pressure 48 psi. Cold and hot starting were still difficult, but the tests could continue.
81-07-02	24588	Recheck timing, all items on specification for gasoline.
81-07-28	24728	Recheck engine tune. Idle speed had increased to 1150 rpm. Timing had retarded to 4°ATDC. Reset to specifications, emissions normal.
81-08-17	24913	Dyno tests were completed. The engine was hard to start both hot and cold. All systems were checked. Injectors were OK on a flow test. The cold start valve operated properly. The auxiliary air valve (fast idle device) tested OK but a new unit was installed. A new control pressure regulator was installed and pressures were to specification. Cold starting was excellent, hot starting still slow.
81-08-21	24950	Emissions check - all to specification.

F.1.3/ Summary

The initial tests on M10 to M50 fuel in 1978 were very successful. The vehicle used the fuel mixtures very efficiently in proportion to the heat content of the fuel mix.

Later, as a result of these tests, fuel component failures became evident. The engine became hard to start, ran on one or two cylinders after starting, and had uneven acceleration. These problems resulted in the vehicle being sent to an independent Volkswagen dealer for repairs. The dealer changed two injectors, the cold start valve, fuel filter, the fuel distributor block and the fuel pump.

On further checking these parts, the only reason found for the vehicle engine malfunction was the fuel distributor block. In this unit the fuel is transmitted to each cylinder from metering slits. Each slit is separated from the others by a neoprene "O" ring. All four "O" rings were in pieces, which classed as an alcohol initiated failure.

These "O" rings were replaced with cut square section rings, made by the author from sheet fluorosilicone rubber, and retained in place by a new fabricated copper retaining ring.

This reworked fuel distributing block had to be installed during the mileage accumulation phase of the Federal-Provincial Alternative Fuel Program.

F.2/ HONDA CVCC ACCORD

F.2.1/ Introduction

This vehicle was acquired used, with 12 000 miles on its odometer. Methanol blends of M10 and M15 were then used in the winter of 1977-78 for about 3000 miles from odometer readings: 12 000 to 15 000 miles. Intermittant use with methanol containing fuels continued until 1979.

This was the first vehicle to start on the Federal-Provincial Methanol Vehicle Test Fuel Program and a brief description of the test history follows.

F.2.2/ CHRONOLOGICAL LIST OF SERVICE ACTIONS: Honda Accord

DATE	ODOMETER (miles)	DESCRIPTION OF EVENT
		Start of Federal-Provincial Alternative Fuel Program.
79-11-9	22813	M15 tests, road and dynamometer.
79-11-12	22942	M10 tests, road and dynamometer.
80-2-5	24812	M15 tests, dynamometer.
80-2-18	25207	M15 tests completed.
80-5-22	26022	M10 road mileage accumulation for approximately 8000 miles from 25 207 miles.
80-9-25	32902	M40 fuel in error due to storage tank stratification problems, but symptoms resulted in the carburetor being dismantled twice, on 80-09-25 and on 80-09-29. When fuel was replaced with gasoline, operation was 98% satisfactory, a slight hesitation on initial acceleration from a stop.
80-11-3	33780	Completion of road mileage, start of repeat dynamometer tests on M10.
80-11-5	33785	Sudden power loss on EPA dynamometer test using M10 fuel. Road test gave a similar result, as of starving of fuel. Adjustment of the float levels in the carburetor did not help the problem. The carburetor was removed and a new one installed, supplied by Ross Davidson of Honda Canada. The vehicle was again readjusted to M10 specifications - Timing 5°BTDC and Dwell 51° Idle (rpm) 850 2500 Emissions HC (ppm) 75 30 CO% 0.2 0.18
80-11-19	34079	Change to M15 fuel and specs. - Timing 6°BTDC Idle (rpm) 850 2500 Emissions HC (ppm) 200 50 CO% 0.2 0.15 Dynamometer M15 tests.
81-02-23	34322	Change to M10 specs. and fuel - dynamometer tests.
81-03-02	34360	Change to gas specs. and fuel Timing 2°BTDC Idle (rpm) 800 2500 Emissions HC (ppm) 150 30 CO% 0.18 0.15 Dyno tests completed for this program.

DATE	ODOMETER (miles)	DESCRIPTION OF EVENT
81-03-16	34496	Change to M10 specifications for vehicle use in general service using M10 fuel.
	35309	Vehicle towed in - high tension coil lead failure to ground. This was replaced with a new wire assembly.
81-06-01	38111	Vehicle returned to section 4413 for general use, M10 fuel being added to tank whenever convenient.
81-11-18	43375	A new head gasket was installed, and vehicle now in service again.

F.3/ VW METHANOL GOLF

F.3.1/ Introduction

Two vehicles were imported. The one belonging to MTC was placed in service and underwent dynamometer testing with results given in the main section of the report. The other vehicle belonged to Transport Canada and has undergone some auxiliary tests.

F.3.2/ CHRONOLOGICAL LIST OF SERVICE ACTIONS: VW Golf (MTC Vehicle)

DATE	ODOMETER (km)	DESCRIPTION OF EVENT
81-10-05	0 to 6381	Break in mileage accumulation M100 fuel. Timing check, 900 rpm, 10° BTDC.
81-11-03	7876	Lost power on Dyno test. Road test indicated fuel filter problem. Filter VW No. 049-129-177A replaced with a 1/4" CANADIAN TIRE plastic unit.
81-11-04	7926	Road Test. Vehicle O.K. Old filter cut apart, heavy grey slime on paper element (probably Aluminum oxide)
81-11-06 to 81-12-03	8086 to 8213	Cold starting tests in trailer at 0°C, M95 fuel (5% isopentane).
81-12-03	8213	Complaint - no idle, stalling. Engine would stall when hot on idle position of accelerator pedal. The carburetor and flexible adapter were removed from the intake manifold. The flexible adapter on the carburetor base had deteriorated, coating the carburetor face with a black sticky deposit and drifting back up the carburetor bore, depositing the same black material on the throttle plate, carburetor bore and idle jet.
81-12-07	8213	The flexible adapter was removed from the carburetor. The fuel bowl cover was removed, the gasket, float and needle and seat were O.K. The air correction jet was removed; a slight corrosion on the end would have no effect on performance. The fuel bowl and contents were clean. The pilot jet was removed; some black material was observed on the end, of no significance, still serviceable. The main fuel jet was removed and was clean, serviceable. Further examination of the flexible adapter, the rubber face next to the carburetor had deteriorated, coating the carburetor flange with the black deposit reported above.
81-12-08	8213	The idle needle was removed (a yellow plastic cover was destroyed to get at this). The needle end was covered with a plastic coating of grey/brown material. The larger air flow needle in the side of the carburetor body was removed (a blue plastic plug cap was destroyed to get at this one). The tapered end of this was covered with similar material as the fuel idle needle, except it had a more fibrous

DATE	ODOMETER (km)	DESCRIPTION OF EVENT
		appearance. The carburetor and some of its parts were soaked in carburetor cleaner 40 min at 18°C and washed with cleaning solvents and all passages blown clear.
81-12-10	8213	The cylinder head was removed from the engine to inspect bore wear.
81-12-14	8213	The cylinder head was taken to the Audio/Visual Section for photos. Measurements of the cylinder head and bore wear were taken. Oil changed to Shell Zero Plus + 1 can Molyslip E.
81-12-15 and 81-12-16	8213	The carburetor parts were cleaned and reassembled. A new aluminum carburetor adapter was made by the MTC machine shop and installed to the carburetor using .02 cm thick fluorosilicone rubber gaskets to replace the flexible adapter.
81-12-22 to 81-12-24	8213	The cylinder head was assembled with new gaskets. The old gasket material was very difficult to remove from the cylinder block. All bolts were torqued to specification. The engine was started but ignition timing problems occurred.
82-01-04	8213	The distributor was reset to proper position and timed to 10° BTDC. On road test, fuel starvation occurred. This was traced to a major amount of grey sludge in the G.M. fuel meter transducer. This was cleaned and reassembled with a new filter and road tested OK. Checked emissions. rpm 1150 3500 CO 0.5% 0.2%
82-01-06	8216	Road test - No idle during warm up and run. Stopped car for 20 min, then no more problems.
82-01-08 to 82-01-21	8226 to 8289	Misc. cold starts and warm up road tests.
82-01-25	8361 to 9103	Dyno tests, commenced for Federal/Provincial Methanol Vehicle Test Program. Complaint - stalling at idle. Readjusted idle screw. Checked emissions. rpm 1000 2500 HC 1200 120 CO 0.45% 0.15%
82-03-09	9103	Added carburetor choke cleaner to fuel line to carburetor (M90 fuel). Idle readjusted to normal.

DATE	ODOMETER (km)	DESCRIPTION OF EVENT
82-03-10	9103	Poor idle in a.m. Recheck all specifications. Timing 9° BTDC. Emissions high again. Readjust idle screw to 1-1/4 turns out. Emissions still high. Removed fuel and air adjusting needles. Both were covered with black deposit. Cleaned and reinstalled both needles. Idle screw adjusted to two turns out, for emissions of 100 ppm HC & 0.55% CO.
82-03-11 to 82-03-24	9104 to 9201	Dyno tests, but poor idle caused termination of tests. The carburetor was removed. Both fuel and air adjusting needles were again dirty. The fuel bowl also contained a lot of dirt. The fuel needle "O" ring was replaced, the original having deteriorated and was broken. Idle surging at 1500 to 1700 rpm now occurred, and any fuel or air adjustments were ineffective in correcting this condition.
82-03-29 to 82-04-13	9201	Removed carburetor again. All passages and jets were recleaned with carburetor choke cleaner and compressed air. When reinstalled, the same surging occurred from 1500 to 1700 rpm. The carburetor from the Federal Golf, license plate number SOV729, was removed and installed on this Vehicle - MTC #81-576-000-89. This ran on fast idle at 1400 rpm with no surging. VW OF AMERICA were contacted by phone and Gus Schumaker recommended checking for vacuum leaks. Consequently, using oil, small leaks were found in the intake manifold and in the carburetor gasket; these were sealed. Idle rpm dropped to 1400 to 1600 rpm but still surging. Idle could be adjusted using the larger air screw to 1000/1100 rpm with surging, but HC and CO emissions were high - 800 ppm and 2% CO.
82-04-06 to 82-04-13	9201 to 9417	All timing marks were checked and found OK. The spark had advanced and was changed to 6° BTDC as per Gus Schumaker's suggestion. The carburetor was removed again, and the air bleed hole in the throttle plate was soldered over. Retested, the idle could be adjusted to 930 rpm, with a very slight surge of 20 rpm. Checked emissions. rpm 930 2500 4000 HC 800 900 900 CO 1.1% .18% .29% Road Test - Stalling on deceleration. The idle screw was readjusted for better idle.
82-04-13	9417	Dyno tests.

DATE	ODOMETER (km)	DESCRIPTION OF EVENT
82-04-15	9516	Complaint - occasional stalling. Idle fuel and air screws readjusted, and stalling problem eliminated, but there is a very fine adjustment between stalling and running. More work needs to be done on this aspect. A full spark advance scan to 4000 rpm was done, both with vacuum advance and without.
82-04-19	9516	Vehicle returned to Dyno for M100 tests.
82-05-12	9742	Complaint - stalling on Dyno Test.
82-05-13	9816	Removed carb and dismantled unit. Traced most passages through carburetor body. No problems found. Three-quarter hour in carb-cleaner; basket removed, washed, all passages blown clear with carburetor choke-cleaner. Finally found idle ports to throttle plate plugged with grey brown hard residue. Some pieces were pushed into port passages and may not have been removed. Reassembled and installed on engine. Started and ran well. Readjust air screw to 1000 rpm, fuel screw to 0.5% CO. Idle now 950 rpm, smooth, road test good.
82-05-14	9830	Readjust CO to minimum rpm 950 Emissions check: rpm 950 2500 4000 CO 0.15% 0.25% 0.8%
82-05-15	9864	After 3/4 hour shutdown, engine stalled on idle, but cleared later. Reset to standard specs as CO is now 2.5%. rpm 975 2500 4000 CO 1.0 .25% .25%
82-05-21	9923	Explo-safe can dumped; grey metallic residue and cloudy fuel sample.
82-05-25	10122	Carburetor idle jets plugged again.
82-05-25	10125	Carburetor removed and dismantled. One small piece of paper-like material was found on the end of the idle fuel metering jet.
82-05-31	10125	Assemble and install carburetor. Filter problem. Installed a new line filter, added a PAL filter unit on the pump to Fluidyne line; road test - same result. Filter problem. Emissions check at idle speed: rpm 920 2500 4000 CO 1.5% 0.22% 0.35%

DATE	ODOMETER (km)	DESCRIPTION OF EVENT
82-05-31	10179	Removed Fluidyne Transducer - filter and float housing full of grey jelly (aluminum corrosion). When this corrosion was removed, many black pits were found in the filter housing recesses. The filter element was clogged completely. A new element was installed. Road test was OK.
82-06-01	10231	The fuel gauge malfunctioned - reads zero.
82-06-07	10308	Dyno test - slipping right hand front tire caused smoke and alarms tripped. Vehicle returned to workshop - no problem found. Rear tires were put on front.
82-06-07	10315	Returned to Dyno for EPA preconditioning. No problem with tires. Operation OK.

F.3.3/ Chronological List of Service Actions:
VW Golf (Transport Canada Vehicle)

DATE	ODOMETER (km)	DESCRIPTION OF EVENT
	0 to	Break-in mileage Oil change to Mobil 1 - 5W30
81-12-08	2359	Synthetic oil. M90 fuel from now on.
82-03-11	2800	Misc Starting tests and demonstrations. CO check OK at 0.8%. Spark advance 12° BTDC, readjusted to 4° BTDC. CO no change.
82-03-12	2907	Fuel filter in line clogged. Replaced with a new unit supplied by VW OF AMERICA.
82-03-06	3600	Emissions check: rpm 820 2500 4000 CO 9% Over 10% Over 10% Miles accumulation continued, idle rough but satisfactory.
82-04-30	5100	M100 fuel for remainder of miles accumulated.
82-05-11	6069	Emissions check. rpm 1000 CO 8 to 9% varying.
82-05-11	6069	Fuel idle screw removed, very dirty with black deposit on end. Air bleed screw removed and hard black deposit on end.
82-05-12	6069	Carburetor removed and dismantled. Idle fuel metering jet had a black material on the end. The lower bore of the carburetor had a black viscous material which was running out of the idle jet ports at the throttle plate area, down the inside of the carburetor and onto the flex adapter, and into the manifold. Deposits are shown in Figures F.1 - F.4
82-05-17	6069	Cleaning up carburetor parts.
82-05-18	6069	Complete cleaning of carburetor in a solution of carburetor choke-cleaner and with compressed air. Assembled and installed on car. Emission check: rpm 930 2500 4000 CO 0.6% 0.5% 2.5% Vehicle taken to Dyno for EPA tests.

DATE	ODOMETER (km)	DESCRIPTION OF EVENT
82-05-24	6220	Vehicle picked up from Dyno; Road test OK.
82-06-01	6354	Emissions Test rpm 930 2500 4000 CO 0.65% 0.2% 1.5%
82-06-07	6388	Timing check and advance curve measured. Timing must be done with the vacuum advance disconnected. The timing was set at the same advance as MTC vehicle 1° BTDC with vacuum advance hose off. The mechanical and vacuum spark advance at all rpms from idle to 4000 rpm was taken. Road test OK.

- Veh - Federal Golf SOV-729
- Fuel - M95, M90, M100
- Odometer 6069 km
- 82-05-12

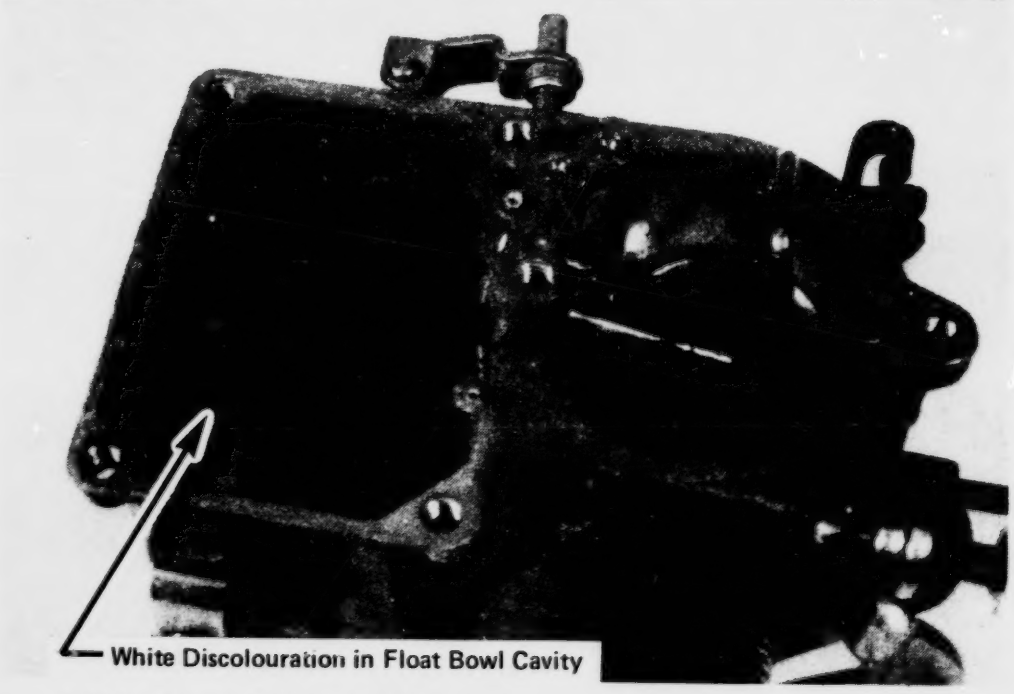
Figure F.1/ Carburetor Fuel Idle Screw

- Veh - Federal Golf SOV-729
- Fuel - M95, M90, M100
- Odometer 6069 km
- 82-05-12

Figure F.2/ Carburetor Air Bleed Screw

- Veh - Federal Golf SOV-729
- Fuel - M95, M90, M100
- Odometer 6069 km
- 82-05-12

Figure F.3/ Carburetor Flexible Adapter



- Veh - Federal Golf SOV-729
- Fuel - M95, M90, M100
- Odometer 6069 km
- 82-05-12

Figure F.4/ Carburetor Bowl Solex 1 BBL

APPENDIX G/
EMISSIONS AND FUEL CONSUMPTION CALCULATIONS

G/ MODIFICATIONS TO EMISSIONS AND FUEL CONSUMPTION CALCULATIONS TO ACCOMMODATE METHANOL HYDROCARBON MIXTURES

G.1/ Calculation of Mass Emissions

Alterations to the Transport Canada procedure [9, 12] are needed for the following:

G.1.1/ Dilution Factor (DF)

This is used to correct the bag analyses for the contribution from the background levels in the ambient air. The assumed value of the maximum CO_2 arising from a stoichiometric mixture, 13.4%, used for gasoline calculations, has to be replaced by a value calculated for methanol hydrocarbon mixtures.

$$DF = \frac{\text{MAX } CO_2\%}{\%CO_2.e + (HC.e + CO.e) \times 10^4}$$

where

HC.e = bag measurement, hydrocarbon (ppm)

CO.e = bag measurement, carbon monoxide (ppm)

$\%CO_2$.e = bag measurement, carbon dioxide %

and, $$\text{MAX } CO_2\% = \frac{(1 + (0.3982 \times MF.M)/(\%C.HC \times MF.HC)) \times 100}{17.16/\%C.HC - 12.40 + (3.40 \times MF.M)/(\%C.HC \times MF.HC)}$$

where:

MF.M = Mass Fraction Methanol

%C.HC = % Carbon in Hydrocarbon Component

MF.HC = Mass Fraction Hydrocarbon Component

G.1.2/ Hydrocarbons

The hydrocarbon mass emission has to be calculated using the percentage of carbon in the mixed fuel and its density.

$$HC.Mass = V.Mix \times Density.HC \times \frac{HC.corr.}{1\ 000\ 000}$$

where:

$$Density.HC = \frac{14.14}{\%C.Mix} \text{ g/cu ft at STP}$$

where:

$$\%C.Mix = MF.HC \times \%C.HC + MF.M \times \%C.M$$

where:

%C.M = % Carbon in Methanol Component

G.2/ Calculation of Fuel Consumption

For hydrocarbon/methanol mixtures:

$$L/100\ km = \frac{((\%C.Mix \times HC) + (0.4286 \times CO) + (0.2727 \times CO_2)) \times 0.06214}{\%C.Mix \times SG.Mix}$$

where:

SG.Mix = Specific Gravity of Mixture

APPENDIX H/

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Table H.1/ Honda Accord: Standard Fuel Consumption Before Mileage Accumulation

BEFORE ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	8.57	2.64	-	-	-	-
90% Confi-dence	0.16	0.04	-	-	-	-
STD. DEV.	0.08	0.02	-	-	-	-
No. of Tests	3	-	-	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	10.16	2.99	-	-	-	-
90% Confi-dence	-	-	-	-	-	-
STD. DEV.	0.82	0.24	-	-	-	-
No. of Tests	2	-	-	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.68	2.78				
90% Confi-dence	-	-	-	-	-	-
STD. DEV.	-	-	-	-	-	-
No. of Tests	1	-	-	-	-	-

AFTER ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/
MEAN	8.81	2.72	6.40	1.97	7.73	2.38
90% Confi-dence	0.41	0.13	0.37	0.11	0.35	0.11
STD-DEV.	0.2	0.06	0.18	0.06	0.17	0.05
No. of Tests	3	-	3	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 00 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.27	2.73	-	-	-	-
90% Confi-dence	0.78	0.23	-	-	-	-
STD. DEV.	0.38	0.11	-	-	-	-
No. of Tests	3	-	-	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.34	2.68	6.74	1.93	7.91	2.27
90% Confi-dence	0.43	0.12	1.11	0.32	0.64	0.19
STD. DEV	0.21	0.06	0.54	0.16	0.31	0.09
No. of Tests	3	-	3	-	-	-

Table H.2/ Honda Accord: Standard Fuel Consumption After Mileage Accumulation

AFTER ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	8.75	2.70	6.44	1.99	7.72	2.38
90% Confid- ence	0.63	0.19	0.45	0.14	0.55	0.17
STD. DEV.	0.31	0.09	0.22	0.07	0.27	0.08
No. of Tests	3	-	3	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.25	2.72	6.98	2.05	8.23	2.42
90% Confi- dence	0.37	0.11	0.10	0.03	0.16	0.05
STD. DEV.	0.18	0.05	0.05	0.01	0.08	0.02
No. of Tests	3	-	3	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.32	2.68	7.20	2.07	8.36	2.40
90% Confi- dence	0.29	0.08	0.16	0.05	0.22	0.06
STD. DEV.	0.14	0.04	0.08	0.02	0.11	0.03
No. of Tests	3	-	3	-	-	-

Table H.3/ VW Rabbit: Standard Fuel Consumption Before Mileage Accumulation

BEFORE ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.33	2.88	6.92	2.13	8.25	2.55
90% Confi-dence	0.37	0.12	1.32	0.41	0.66	0.20
STD. DEV.	0.18	0.06	0.64	0.19	0.32	0.09
No. of Tests	3	-	3	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.73	2.86	6.92	2.04	8.47	2.49
90% Confi-dence	0.39	0.11	0.81	0.24	0.58	0.17
STD. DEV.	0.19	0.06	0.39	0.12	0.28	0.08
No. of Tests	2	-	2	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.75	2.80	6.94	1.99	8.49	2.44
90% Confi-dence	0.12	0.04	1.28	0.37	0.64	0.18
STD. DEV.	0.06	0.02	0.62	0.18	0.31	0.09
No. of Tests	2	-	2	-	-	-

AFTER ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.05	2.79	6.48	2.00	7.89	2.43
90% Confi-dence	0.41	0.13	0.46	0.14	0.42	0.13
STD. DEV.	0.20	0.06	0.22	0.07	0.21	0.06
No. of Tests	3	-	3	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.44	2.78	6.70	1.97	8.21	2.42
90% Confi-dence	0.12	0.04	0.23	0.07	0.04	0.01
STD. DEV.	0.06	0.02	0.11	0.03	0.02	0.006
No. of Tests	3	-	3	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.54	2.74	6.72	1.93	8.27	2.38
90% Confi-dence	0.68	0.20	0.24	0.08	0.35	0.10
STD. DEV.	0.33	0.09	0.12	0.04	0.17	0.05
No. of Tests	3	-	3	-	-	-

Table H.4/ VW Rabbit: Standard Fuel Consumption After Mileage Accumulation

AFTER ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.08	2.80	6.47	2.00	7.91	2.44
90% Confid-ence	2.26	0.69	0.86	0.27	1.62	0.51
STD. DEV.	1.11	0.34	0.42	0.13	0.80	0.25
No. of Tests	3	-	3	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.43	2.78	6.66	1.96	8.18	2.41
90% Confi-dence	0.71	0.21	0.12	0.04	0.45	0.13
STD. DEV.	0.35	0.10	0.06	0.02	0.22	0.06
No. of Tests	3	-	3	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	9.23	2.65	6.31	1.81	7.91	2.27
90% Confi-dence	0.32	0.09	0.54	0.16	0.41	0.12
STD. DEV.	0.16	0.04	0.27	0.08	0.21	0.06
No. of Tests	3	-	3	-	-	-

Table H.5/ Ford Fairmont: Standard Fuel Consumption Before Mileage Accumulation

BEFORE ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	11.57	3.57	8.67	2.67	10.27	3.17
90% Confid-ence	0.57	0.18	0.92	0.28	0.57	0.18
STD. DEV.	0.28	0.09	0.45	0.14	0.28	0.09
No. of Tests	3	-	3	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	12.94	3.81	10.01	2.95	11.62	3.42
90% Confi-dence	0.61	0.18	0.37	0.11	0.51	0.15
STD. DEV.	0.30	0.09	0.18	0.05	0.25	0.07
No. of Tests	2	-	2	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	12.75	3.66	9.95	2.86	11.49	3.30
90% Confi-dence	0.08	0.02	0.16	0.05	0.44	0.12
STD. DEV.	0.04	0.01	0.08	0.02	0.22	0.06
No. of Tests	3	-	3	-	-	-

AFTER ENGINE ADJUSTMENT

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	12.05	3.55	9.33	2.78	10.82	3.18
90% Confi-dence	0.55	0.16	0.85	0.25	0.16	0.05
STD. DEV.	0.27	0.08	0.42	0.12	0.08	0.02
No. of Tests	3	-	3	-	-	-

Table H.6/ Ford Fairmont: Standard Fuel Consumption After Mileage Accumulation

BEFORE ENGINE ADJUSTMENT

	GAS					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	12.14	3.75	9.46	2.92	10.77	3.32
90% Confi-dence	0.56	0.17	0.88	0.28	0.74	0.22
STD. DEV.	0.28	0.09	0.44	0.14	0.37	0.11
No. of Tests	3	-	3	-	-	-

	M10					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	12.46	3.67	10.04	2.95	11.37	3.35
90% Confi-dence	0.64	0.19	0.50	0.15	0.32	0.09
STD. DEV.	0.32	0.09	0.25	0.07	0.16	0.05
No. of Tests	3	-	3	-	-	-

	M15					
	URBAN		HWY		COMBINED	
	L/ 100 km	MJ/km	L/ 100 km	MJ/km	L/ 100 km	MJ/km
MEAN	12.48	3.58	9.93	2.85	11.33	3.25
90% Confi-dence	1.01	0.29	0.88	0.25	0.90	0.26
STD. DEV.	0.51	0.15	0.44	0.13	0.45	0.13
No. of Tests	3	-	3	-	-	-

Table H.7/ VW Golf Methanol Vehicle: Standard Fuel Consumption

STANDARD CARBURETOR

	M90					
	URBAN		HWY		COMBINED	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
Mean	14.73	2.65	11.20	2.02	13.15	2.37
90% Confid-ence	0.90	0.16	0.87	0.16	0.75	0.14
STD. DEV.	0.45	0.08	0.43	0.08	0.38	0.07
No. of Tests	3	-	3	-	-	-

LEAN CARBURETOR

	M90					
	URBAN		HWY		COMBINED	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
MEAN	14.54	2.62	10.31	1.86	12.63	2.27
90% Confi-dence	0.72	0.13	0.96	0.17	0.84	0.15
STD. DEV.	0.36	0.06	0.48	0.09	0.42	0.08
No. of Tests	3	-	3	-	-	-

	M100					
	URBAN		HWY		COMBINED	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
MEAN	14.94	2.49	10.82	1.81	13.08	2.18
90% Confi-dence	1.08	0.18	0.72	2.12	0.86	0.14
STD. DEV.	0.54	0.09	0.36	0.06	0.43	0.07
No. of Tests	3	-	3	-	-	-

	M100					
	URBAN		HWY		COMBINED	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
MEAN	14.92	2.49	10.37	1.70	12.87	2.15
90% Confi-dence	0.76	0.13	0.50	0.08	0.62	0.10
STD. DEV.	0.38	0.06	0.25	0.04	0.31	0.05
No. of Tests	3	-	3	-	-	-

TABLE H.8/ Exhaust Emissions -- Before Mileage Accumulation

Vehicle: Honda Accord

BEFORE ENGINE ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.16	0.10	0.05	3
CO	7.41	0.74	0.36	3
NO_x	1.88	0.28	0.14	3

AFTER ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.28	0.60	0.29	3
CO	8.60	3.09	1.50	3
NO_x	1.59	0.21	0.10	3

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	3.41	2.42	1.42	2
CO	10.0	1.08	0.54	2
NO_x	3.36	0.06	0.03	2

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.73	1.38	0.63	3
CO	6.79	0.19	0.09	3
NO_x	1.27	0.16	0.08	3

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	3.84	-	-	1
CO	8.59	-	-	1
NO_x	1.74	-	-	1

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.00	0.43	0.21	3
CO	5.88	0.54	0.26	3
NO_x	1.18	0.39	0.19	3

TABLE H.9/ Exhaust Emissions -- After Mileage Accumulation

Vehicle: Honda Accord

AFTER ENGINE ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.96	0.20	0.10	3
CO	8.57	4.47	2.19	3
NO_x	1.80	0.49	0.24	3

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.52	0.22	0.11	3
CO	4.41	1.0	0.49	3
NO_x	1.64	0.37	0.18	3

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.67	0.02	0.01	3
CO	5.18	0.43	0.21	3
NO_x	1.40	0.10	0.05	3

TABLE H.10/ Exhaust Emissions -- Before Mileage Accumulation

Vehicle: VW Rabbit

BEFORE ENGINE ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.29	0.10	0.05	3
CO	5.33	0.66	0.32	3
NO_x	2.80	0.29	0.14	3

AFTER ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.37	0.23	0.11	3
CO	7.16	0.77	0.37	3
NO_x	2.60	0.27	0.13	3

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.35	0.06	0.03	2
CO	6.20	0.64	0.31	2
NO_x	2.21	0.02	0.01	2

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.50	0.17	0.08	3
CO	4.93	1.97	0.95	3
NO_x	3.13	0.06	0.03	3

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	2.98	0.43	0.21	2
CO	3.64	0.62	0.30	2
NO_x	1.94	0.08	0.04	2

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	3.12	0.72	0.35	3
CO	3.77	0.50	0.24	3
NO_x	2.38	0.17	0.08	3

TABLE H.11/ Exhaust Emissions -- After Mileage Accumulation

Vehicle: VW Rabbit

AFTER ENGINE ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.39	0.10	0.05	3
CO	16.20	6.73	3.30	3
NO_x	2.49	1.16	0.57	3

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.30	0.39	0.19	3
CO	8.19	0.19	0.09	3
NO_x	3.19	0.06	0.03	3

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	1.57	0.12	0.06	3
CO	5.58	0.43	0.21	3
NO_x	2.20	0.55	0.27	3

TABLE H.12/ Exhaust Emissions -- Before Mileage Accumulation

Vehicle: Ford Fairmont

BEFORE ENGINE ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.41	0.01	0.005	3
CO	4.53	1.57	0.77	3
NO_x	0.79	0.06	0.03	3

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.326	0.10	0.05	2
CO	4.23	0.92	0.45	2
NO_x	1.15	0.15	0.07	2

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.25	0.06	0.03	3
CO	2.60	0.45	0.22	3
NO_x	1.27	0.80	0.39	3

AFTER ENGINE ADJUSTMENT

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.46	0.18	0.09	3
CO	4.17	2.84	1.39	3
NO_x	1.14	0.12	0.06	3

TABLE H.13/ Exhaust Emissions -- After Mileage Accumulation

Vehicle: Ford Fairmont

BEFORE ENGINE ADJUSTMENT

GAS	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.62	0.14	0.07	3
CO	7.33	5.60	2.82	3
NO_x	1.50	0.04	0.02	3

M10	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.12	0.02	0.01	3
CO	4.06	0.08	0.04	3
NO_x	1.75	0.16	0.08	3

M15	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	0.41	0.02	0.01	3
CO	3.80	0.02	0.01	3
NO_x	2.11	0.26	0.13	3

TABLE H.14/ Exhaust Emissions -- (Standard and Lean Carburetor)

Vehicle: VW Golf

STANDARD CARBURETOR

M90	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	8.35	2.27	1.14	3
CO	34.39	13.11	6.56	3
NO_x	1.92	0.38	0.19	3
HCHO	0.77	0.28	0.14	3

LEAN CARBURETOR

M90	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	6.77	0.42	0.21	3
CO	19.36	12.22	6.4	3
NO_x	1.27	0.28	0.14	3
HCHO	0.71	0.36	0.18	3

M100	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	9.08	2.84	1.42	3
CO	11.39	3.10	1.55	3
NO_x	1.08	0.70	0.35	3
HCHO	0.82	0.41	0.21	3

M100	MEAN g/mile	90% CONFIDENCE	STANDARD DEVIATION	NO. OF TESTS
HC	7.85	0.90	0.45	3
CO	8.83	0.76	0.38	3
NO_x	1.06	0.16	0.08	3
HCHO	0.68	0.24	0.12	3

Table H.15/ Fuel Consumption at Constant Speed -- Before Engine Adjustment

Vehicle: Honda Accord

SPEED km/h	GAS		M10		M15	
	Fuel Consumption		Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
32	5.30	1.64	5.96	1.75	6.05	1.74
48	5.04	1.56	5.61	1.65	5.70	1.64
64	5.27	1.63	5.73	1.68	5.87	1.68
80	5.86	1.81	6.01	1.77	6.22	1.78
97	6.15	1.90	6.39	1.88	6.88	1.98
113	7.45	2.29	8.01	2.36	8.31	2.38

Table H.16/ Fuel Consumption at Constant Speed -- After Engine Adjustment

Vehicle: Honda Accord

SPEED km/h	GAS		M10		M15	
	Fuel Consumption		Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
32	4.85	1.49	5.12	1.51	5.17	1.48
48	4.61	1.42	5.01	1.48	5.10	1.47
64	4.85	1.49	5.22	1.54	5.58	1.60
80	5.70	1.76	5.78	1.70	6.45	1.55
97	6.09	1.88	6.33	1.86	6.79	1.95
113	7.36	2.27	7.86	2.31	8.17	2.35

Table H.17/ Fuel Consumption at Constant Speed -- Before Engine Adjustment

Vehicle: VW Rabbit

SPEED km/h	GAS		M10		M15	
	Fuel Consumption		Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
32	7.74	2.38	7.76	2.34	8.18	2.35
48	5.64	1.74	5.99	1.76	6.12	1.76
64	5.97	1.84	6.31	1.86	6.57	1.88
80	6.54	2.02	6.94	2.04	7.00	2.01
97	7.72	2.38	8.17	2.40	8.18	2.35
113	9.03	2.79	9.79	2.88	9.95	2.86

Table H.18/ Fuel Consumption at Constant Speed -- After Engine Adjustment

Vehicle: VW Rabbit

SPEED km/h	GAS		M10		M15	
	Fuel Consumption		Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
32	7.88	2.43	7.90	2.33	7.66	2.20
48	5.84	1.80	5.95	1.75	6.08	1.75
64	6.13	1.89	6.55	1.93	6.79	1.95
80	6.65	2.05	7.08	2.08	7.49	2.15
97	7.76	2.39	8.25	2.42	8.34	2.40
113	9.32	2.88	9.87	2.91	10.22	2.94

Table H.19/ Fuel Consumption at Constant Speed -- Before Engine Adjustment

Vehicle: Ford Fairmont

SPEED km/h	GAS		M10		M15	
	Fuel Consumption		Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
32	8.17	2.52	8.58	2.52	8.38	2.41
48	7.47	2.31	8.53	2.51	8.50	2.44
64	8.00	2.47	8.38	2.46	8.61	2.47
80	8.90	2.75	9.48	2.79	9.49	2.73
97	10.61	3.27	11.06	3.25	10.92	3.14
113	11.85	3.66	12.31	3.62	-	-

Table H.20/ Fuel Consumption at Constant Speed -- After Engine Adjustment

Vehicle: Ford Fairmont

SPEED km/h	GAS		M10		M15	
	Fuel Consumption		Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km	L/100 km	MJ/km
32	-	-	8.50	2.50	-	-
48	-	-	8.51	2.50	-	-
64	-	-	8.85	2.60	-	-
80	-	-	9.96	2.93	-	-
97	-	-	11.47	3.37	-	-
113	-	-	-	-	-	-

Table H.21/ Fuel Consumption at Constant Speed -- (Standard Carburetor)

Vehicle: VW Golf

SPEED km/h	M90		M100	
	Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km
32	-	-	-	-
48	8.23	1.48	8.75	1.46
64	9.85	1.77	9.55	1.59
80	11.32	2.04	10.50	1.75
97	14.05	2.53	13.05	2.18
113	-	-	-	-

Table H.22/ Fuel Consumption at Constant Speed -- (Lean Carburetor)

Vehicle: VW Golf

SPEED km/h	M90		M100	
	Fuel Consumption		Fuel Consumption	
	L/100 km	MJ/km	L/100 km	MJ/km
32	-	-	-	-
48	8.97	1.61	9.12	1.52
64	9.47	1.70	9.40	1.57
80	10.74	1.93	10.71	1.79
97	12.41	2.23	12.74	2.13
113	-	-	-	-

TABLE H.23/ Driveability (Before Engine Adjustment)

Vehicle: Honda Accord

COLD START	GAS	M10	M15
Mean Total Demerits	160	237	302
90% Confidence	---	120.1	129.5
Standard Deviation	---	60	62.9
No. of Tests	1	3	3

HOT START	GAS	M10	M15
Mean Total Demerits	75	163	132
90% Confidence	95.9	---	---
Standard Deviation	46.7	---	---
No. of Tests	2	1	1

TABLE H.24/ Driveability (After Engine Adjustment)

Vehicle: Honda Accord

COLD START	GAS	M10	M15
Mean Total Demerits	135	150	204
90% Confidence	---	97.6	97.6
Standard Deviation	---	47.4	41.3
No. of Tests	1	2	4

HOT START	GAS	M10	M15
Mean Total Demerits	90	80	45
90% Confidence	---	21.4	95.9
Standard Deviation	---	10.6	46.6
No. of Tests	1	2	4

TABLE H.25/ Driveability (After Mileage Accumulation)

Vehicle: Honda Accord

COLD START	GAS	M10	M15
Mean Total Demerits	175	205	235
90% Confidence	61.4	51.4	48.3
Standard Deviation	30.1	25.2	23.7
No. of Tests	3	3	3

HOT START	GAS	M10	M15
Mean Total Demerits	85	95.3	95.2
90% Confidence	51	30.8	57.5
Standard Deviation	25	15.1	28.2
No. of Tests	3	3	3

TABLE H.26/ Driveability (Before Engine Adjustment)

Vehicle: VW Rabbit

COLD START	GAS	M10	M15
Mean Total Demerits	150	145	115
90% Confidence	56.9	81.5	10.3
Standard Deviation	27.5	39.4	5.0
No. of Tests	3	3	3

HOT START	GAS	M10	M15
Mean Total Demerits	130	163	117
90% Confidence	58.0	44	67
Standard Deviation	28.4	21.5	32.5
No. of Tests	3	3	3

TABLE H.27/ Driveability (After Engine Adjustment)

Vehicle: VW Rabbit

COLD START	GAS	M10	M15
Mean Total Demerits	82	103	120
90% Confidence	49.6	67.3	43.3
Standard Deviation	24.1	32.5	21.0
No. of Tests	3	3	3

HOT START	GAS	M10	M15
Mean Total Demerits	100	146	152
90% Confidence	61.8	73.6	37.2
Standard Deviation	30.1	35.6	18.1
No. of Tests	3	3	3

TABLE H.28/ Driveability (After Mileage Accumulation)

Vehicle: VW Rabbit

COLD START	GAS	M10	M15
Mean Total Demerits	141	145	158
90% Confidence	38.56	45.5	46.4
Standard Deviation	18.9	22.3	22.7
No. of Tests	2	2	2

HOT START	GAS	M10	M15
Mean Total Demerits	100	122	135
90% Confidence	41.2	27.3	55.5
Standard Deviation	20.2	13.1	27.2
No. of Tests	2	2	2

TABLE H.29/ Driveability (Before Engine Adjustment)

Vehicle: Ford Fairmont

COLD START	GAS	M10	M15
Mean Total Demerits	140	148	159
90% Confidence	37.3	41.2	53.9
Standard Deviation	18.3	20.2	26.4
No. of Tests	3	3	3

HOT START	GAS	M10	M15
Mean Total Demerits	156	130	150.3
90% Confidence	24.45	41.4	56.7
Standard Deviation	12.0	20.3	27.8
No. of Tests	3	3	3

Table H.30/ Driveability (After Engine Adjustment)

Vehicle: Ford Fairmont

COLD START	GAS	M10	M15
Mean Total Demerits	-	150	-
90% Confidence	-	61.2	-
Standard Deviation	-	30	-
No. of Tests	-	3	-

HOT START	GAS	M10	M15
Mean Total Demerits	-	133	-
90% Confidence	-	52.4	-
Standard Deviation	-	25.7	-
No. of Tests	-	2	-

TABLE H.31/ Driveability (After Mileage Accumulation)

Vehicle: Ford Fairmont

COLD START	GAS	M10	M15
Mean Total Demerits	110	145	150
90% Confidence	25.2	40.0	42.8
Standard Deviation	12.6	20.0	21.4
No. of Tests	3	3	3

HOT START	GAS	M10	M15
Mean Total Demerits	100	146	145
90% Confidence	26.2	42.2	37.4
Standard Deviation	13.1	21.1	18.7
No. of Tests	3	3	3

TABLE H.32/ Driveability (Standard Carburetor)

Vehicle: VW Golf

COLD START	M90	M100
Mean Total Demerits	245	285
90% Confidence	35	45
Standard Deviation	16.5	22.5
No. of Tests	2	2

HOT START	M90	M100
Mean Total Demerits	135	125
90% Confidence	27	25
Standard Deviation	13.5	12.5
No. of Tests	2	2

TABLE H.33/ Driveability (Lean Carburetor)

Vehicle: VW Golf

COLD START	M90	M100
Mean Total Demerits	215	265
90% Confidence	42.5	50.0
Standard Deviation	21.3	25.0
No. of Tests	2	2

HOT START	M90	M100
Mean Total Demerits	140	155
90% Confidence	31.0	35
Standard Deviation	15.5	17.5
No. of Tests	2	2

Table H.34/ Equivalence Ratio Measurements at 80 km/h

	GAS	M10	M15	M90	M100
HONDA ACCORD					
ORSAT	1.24	1.31	1.33	-	-
VW RABBIT					
ORSAT	0.99	1.06	1.07	-	-
FAIRMONT					
ORSAT	0.98	0.97	0.95	-	-
BECKMAN	0.978	0.963	0.98		
VW GOLF					
BECKMAN Standard	-	-	-	0.810	0.924
Lean				0.920	1.034